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SALINITY MANAGEMENT ALTERNATIVES FOR THE RECHNA DOAB, PUNJAB, PAKISTAN

Volume Two

History of Irrigated Agriculture: A Select Appraisal

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FOREWORD

This report is one of eight volumes under the umbrella title "Salinity Management Alternatives for the Rechna Doab, Punjab, Pakistan." The funding for this effort has been provided by the Government of The Netherlands through the Royal Netherlands Embassy in Islamabad under the Phase II project, "Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan." Between 1989-93, IIMI operated three field stations in Rechna Doab using Dutch phase I funding; much of this field data has been incorporated into this study.

Rechna Doab, the ancient floodplain between the Ravi and Chenab rivers covering a gross area of 2.9 Mha, is one of the most intensively developed irrigated area within the country. With over a century of modern irrigation development, primarily by diversions from the Chenab River, agricultural productivity was continually bolstered. Then, some localities were beset with the threats of higher subsurface water levels and soil salinization. The public sector responded by implementing Salinity Control and Reclamation Projects (SCARPs) beginning in 1960. These projects, plus a huge increase in private tubewell development since 1980, have lowered subsurface water levels; however, the use of poor quality tubewell water, particularly in the center of the Doab, has resulted in secondary salinization. This study is an integrated attempt across both space and time to address the systems responsiveness to the abovementioned concerns.

Vast amounts of data have been collected by public agencies in this study area since 1960. There are a number of agriculture census reports (1960, 1972, 1980 and 1990). Also, the Water and Power Development Authority (WAPDA) has done extensive investigations; their data were made available to IIMI through the General Management (Planning) and the SCARPs Monitoring Organization (SMO). In addition, WAPDA deputed an engineer half-time to participate in these studies who is knowledgeable on the Indus Basin Model Revised (see Volume Eight), which was used primarily to study the effect of groundwater balance constraints on cropping patterns.

The planning for this study was done during January-March 1995. Then, spatial database manipulations using GIS tools were employed to provide the base stratifications leading to the selection of sample sites for IIMI's field campaigns during 1995, which were meant to corroborate, and in many instances update, the information already gathered from public sources. This included, in addition to structured farmer interviews, physical observations on the useable pumped water quality, soil salinity, surface soil texture, and cropping patterns.

This integrated approach involves a synthesis of spatial modeling comprising drainage, salinity, and groundwater use constraints with a calibrated groundwater salinity model, a root zone surface and groundwater balance model, and production function models appropriate to the agroecology of the area. The output provides both suggestive and predictive links to the sustainability of irrigated agriculture in the Rechna Doab.

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Volume Two

HISTORY OF IRRIGATED AGRICULTURE: A SELECT APPRAISAL

PART A

I. PREAMBLE

A. The Sustainability Realization

Agriculture continues to be the largest single sector and the driving force of Pakistan's economy, accounting for 26% of GDP and, together with agro-based industries, contributing 80% of export earnings (IFAD, 1992). Over half the labor force is absorbed by the sector which has been performing below potential as a result of various technical, social and structural constraints. The sector as a whole is passing through a transitional phase from subsistence to increasingly commercial production (grain crops to cash crops) and the Governmnet has directly or indirectly abetted in this process through regulatory control over resource allocation (land, water) and market pricing). However, there are physical limits to the extent where the system can achieve self-sufficiency, not least of which contitutes the issue of optimal distribution of water resources across an increasingly fragmented agricultural land. While this constrains the homogeneous returns on the value-added investments into this sector, it also raises doubts about the sustainability of these returns over the long run, especially when much of the systems' productive flexibility is lost to continuing centralization of resources and authority. The emergent realizations must then explore this internal latitude within the system and take the emphasis away from passively responding to resource depletion. This is especially true for the irrigated regime where the situation could be likened to burning the candle at both ends; while the land fragmentation (more than 38% under 5 ha of holding) depletes from one end under continuing acceptance of subsistence, the scarcity and quality of primary input (irrigation supplies) hamper both intensive and extensive growth of agriculture.

Our past understanding of the gains from the ***irrigation*** system have mainly stemmed from the perspective of capital investments. The hindsight on long term resource mobilization and alternatives for its depletion have been largely remiss under the domineering influence of benefit-to-cost ratios rated over the project lives. This strategy, capitalizing on project worthiness of a situation, actually begets additional projects to overcome the deficiencies of the short term goals established earlier (e.g. many of the completed SCARPs undergoing focused rehabilitation). In fact, the culmination of the major capital investments should automatically lead to management oriented sustainable strategies, which is not often the case. The issue is not that feasibility studies tend to be over-optimistic about the project benefits, but the lack of original investment needed to keep the disbenefits from dominating case. The issue is not that feasibility studies tend to be over-optimistic about the project benefits, but the lack of original investment needed to keep the disbenefits from dominating the overall resource generation. Thus said, the daunting task confronting the long term policy planners is the balance between ambitious capital investments (passive responsiveness to resource degeneration) and the modicum of safeguards promoting sustainability beyond project life. The tailorings of this approach should best learn from past public sector mistakes, and preferably across domains where the irrigation system is beyond the evolutionary stages.

B. The Rechna Doab: Lead to Integrated Analysis

Perhaps an impartial assessment of the most likely outcome of irrigation systems rehabilitation projects is afforded by institutions that have not been affiliated with its development but have had the opportunity to monitor the progressive realizations over and beyond the project life. It is not a coincidence that the International Irrigation Management Institute's non-capital intensive mandate in Pakistan has allowed it to study one of the most intensively developed irrigated areas within the country. Rechna Doab has had over a 100 years of history to itself, and has also been the starting point for the public sector land reclamation schemes within the country (SCARPs). As of now, following two decades of large reclamation projects since 1960, there are still small pilot projects operating across its landscape for which IIMI's country office has been able to substantiate the potential gains in crop productivity (wheat-rice in the north and mixed in the south) through its field presence both in the center and the south of the Lower Chenab Canal Irrigation Circle.

This study on Salinity Management Alternatives for the Rechna Doab is an integrated attempt across both space and time to address the systems responsiveness to the nexus of the above mentioned concerns. The study regime, the land between the Ravi and Chenab rivers in north central Pakistan (Figure 1) represents the appropriate mix of threats to the physical sustainability of the system that are found to varying degrees elsewhere in the Indus plains. In addition to the land reclamation attempts, several public sector research organizations also have mobilized adaptive research programs that are spread across the 2.9 Mha gross area of this doab. In fact, the locus of this research effort is spearheaded by a host of public institutions concentrated in the city of Faisalabad located in the center of the doab. These institutions continually add to one of the most exhaustive public sector archives on soil and crop investigations specific to the Rechna Doab.

In comparison, IIMI's site-specific contributions to the emergent management of the irrigation system across selected locales of the LCC system are a microcosm. But even this limited collection of data on the variability of system-wide irrigation flows and the resultant impact at farmgate deliverables has been impressive on the need for more than imperative system rehabilitation needs that are different from the purely engineering focus of more than three decades ago. The findings from IIMI's field presence between 1987-93 have been suggestive towards a delinking of the irrigation supplies from the outdated objectives of

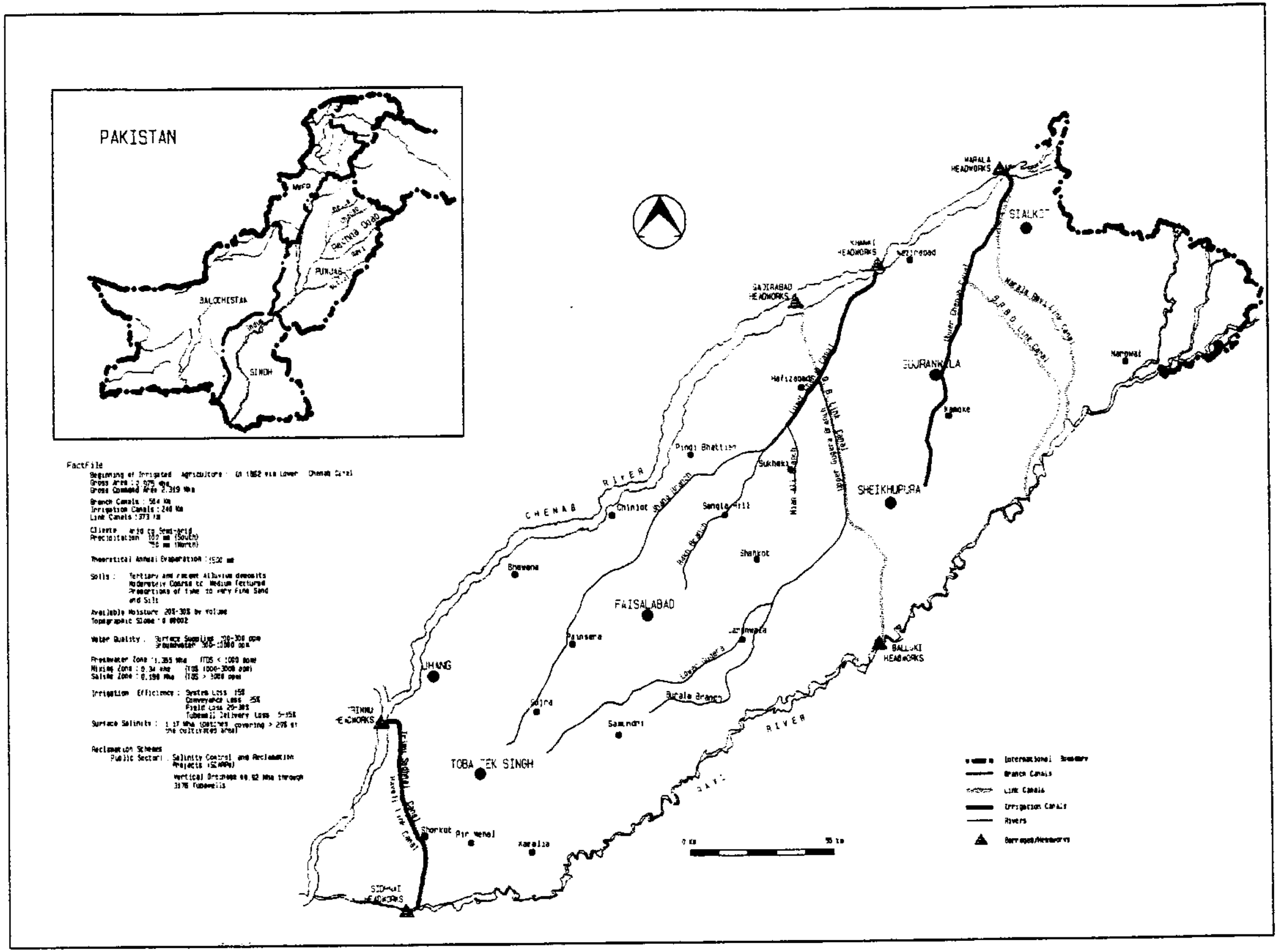


Figure 1 Hydrological Layout of Rechna Doab, Punjab, Pakistan.

system wide equity criteria and its utilization from the sustainability point of view. This realization, in the absence of stringent distribution controls, will largely dictate the optimal allocation of scarce irrigation supplies coming forth through an ageing distribution system already stressed by extended full supply operations.

In the discussion that follows, the emphasis is not necessarily restricted to the irrigation systems profile of the Rechna Doab, at least not from the outset. The developments elsewhere across the Indus Basin resulting from irrigation system rehabilitation works served as the macro-level stimulator of agricultural productivity within the Rechna Doab. With issues of land degradation emerging in tandem with the increase in agricultural intensity, the focus will shift to the most significant threats to the sustainability of the system and the scope of rehabilitation efforts therein.

II. THE MACRO PERSPECTIVE

A. Irrigation System

The Indus Basin is a huge plain crossed by the Indus, Jhelum, Chenab, Sutlej, Ravi, and Beas rivers (Figure 2). The climate is arid to semi arid, with low and extremely unreliable rainfall, thus necessitating some form of irrigation as a basis for stable agriculture. Since 1947, Pakistan with the aid of international donors has remodeled, expanded, and integrated the irrigation system of the country. This was largely facilitated due to the World Bank brokered Indus Waters Treaty in 1960 between Pakistan and India that allowed Pakistan the right to develop irrigation water storage and diversion infrastructures on the three western rivers (Indus, Jhelum, Chenab). These structures largely capitalize on the monsoonal flooding to store precious supplies for the winter crops.

The land between the rivers includes areas in the central portions that are above the flood plains. These high areas are called bar. Before the modern irrigation system, these bar were covered by grassy and woody vegetation. They were exploited by semi-nomadic people with large herds of camels, sheep, goats, and cattle. These people also engaged in some rainfall agriculture, and cultivated small parcels of land irrigated by Persian wheel wells, an endless chain of pots worked by a gear and shaft mechanism and powered by yoked animals. These wells were often 15-30 meters deep. With river water regulation, these areas have experienced intensive cultivation.

1) Delivery Mechanisms

The system of dams and link canals resulting from the constructions under the Indus Waters Treaty have yielded an elaborate network of water distribution that carries the reach-specific

FACTFILE

Gross Area : 79.66 Mha
Size of Indus Basin : 16.2 Mha
Culturable Area : 13.55 Mha
Major River Systems : Indus, Jhelum, Chenab, Ravi, Sutlej
Major Reservoirs : Tarbela, Mangla, Warsak
Reservoir Inflows : Tarbela 72.92 b m3, Mangla 27.97 b m3, Warsak 19.46 b m3
Barrages/Headworks : 19
Diversion Capacity : 7318 m3/s
Link Canals : 12
Irrigation Canals : 43
Watercourses : 89100
Conveyance System : 38000 Km
Watercourse System : 1.6 Million Km
Surface Drainage : 6500 Km

Climate : Arid Subtropical
Annual Precipitation 100 mm in the South, 1000 mm in the North

Average Annual Surface Flows : 175 b m3

Western River Flows : 158 b m3

Average Annual Water Utilization : 123.4 b m3

Annual Groundwater Recharge : 56 b m3

Groundwater Pumpage for Irrigation : 45 b m3

Fresh water Zone : 33% of Indus Basin
Moderately Saline : 13%
Highly Saline : 54%

Ratio of Irrigated to Cultivated Land : 78%

Design Irrigation Intensity : 75% to 120%

Typical Water Duty : 210-280 l/s/1000 ha

Public Tubewells : 12500 (56-142 l/s)
Private Tubewells : 300000 (26-60 l/s)

Area Affected by High Water Table : 2.2 Mha

Area Affected by Moderate to High Levels of Salinity : 2.4 Mha

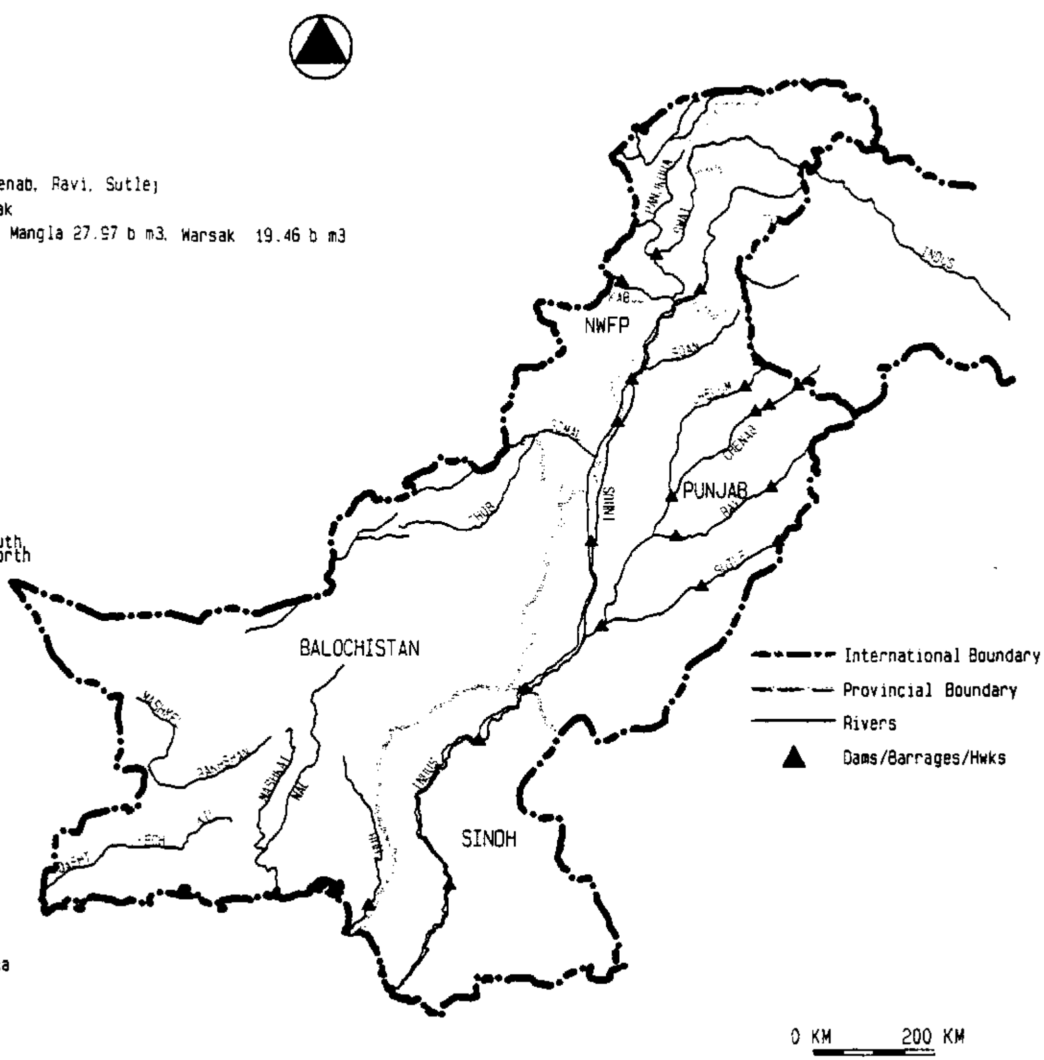


Figure 2 Hydrological Layout of Pakistan.

excess flows from the western rivers to the eastern river beds and canals. These are today components of the largest single integrated irrigation system in the world comprising 43 canal commands with over 63,000 km of distribution to about 107,000 watercourses. About 16.2 million hac. are irrigated by the system.

The system uses barrages for canal diversions designed for continuous operation at or near full capacity. The amount of flow cannot be regulated on demand except within very narrow parameters. Water flows continuously from canals into distributaries, then through ungated concrete modular outlets (moghas) into watercourses, and finally into farmers' ditches and fields. The mogha is designed to deliver a fixed quantity of water when the canal is flowing at a full capacity based on the area commanded. Although there is great variation in area irrigated and number of farmers, each watercourse commands on the average about 225 hac. cultivated by about 50 farmers.

2) Administrative Control

The Provincial Irrigation Departments (PIDs) are responsible for operating and maintaining the system downward from the barrages to the moghas. Thereonwards, the watercourse is legally the responsibility of the farmers who own land in the command area. The water distribution was deliberately designed by the British to command the maximum area possible (0.21 lps/ha) with a minimum of management necessary upto the mogha. Despite major remodelling at the macro level, canals are still operated according to the principals established by the British.

The Irrigation Department retains considerable residual power, set out in the Canal and Drainage Act of 1873 (Jahania, 1973). This power is used only when the shareholders appeal to the Irrigation Department. Similarly, the extension of irrigation included no instructions to the farmers on irrigation techniques. Farmers were left to their own devices (Johnson et al., 1977). The major method continues to consist of the flooding of small basins. There is no adequate means of communicating information from the users to the higher level managers, or even from the top-down. Finally, no, efforts have been made to organize farmers locally on either a formal or informal basis to manage the watercourses. The watercourse is a collective or "public good" which benefits all farmers using it, but there is no mechanism to insure that each contributes his shares to its maintenance (Olson, 1965; Lowdermilk et al., 1978).

3) Inception Considerations

The British began planning canal projects even before formally annexing the Punjab in 1849. The first canal, the Upper Bari Doab, began irrigating in 1861. Thereafter, the British continued building increasingly sophisticated and large-scale canals until the Partition.

The British had several motives for building the canal system. In the beginning, there was an idealistic and enthusiastic desire to extend irrigation to demonstrate the benefits of European science. A decisive motive for the first canal was to give employment to potentially disruptive Sikh army veterans. Another more important and lasting motive was to improve the agricultural value and thus the revenue-producing capacity of the newly annexed lands. Yet another motive was fear of famine (Michel 1967:65-66).

The earlier canals were mostly designed to improve agriculture in already settled areas. Later projects emphasized settling new waste lands, which involved not only canal building but laying out of new villages, cities, roads, railroads, etc., and distribution of land to settlers. The British hoped to reduce famine in India by making Punjab the "Granary of India" and to relieve overpopulation in eastern districts of Punjab by settling farmers from these areas on new lands.

The British engineers who built the system had no previous experience in building irrigation works. When they began, they had little theoretical knowledge of hydraulics, and knew little about groundwater hydrology and the like (Michel 1967:50-51). Furthermore, modern construction technology, as machinery and building materials, was not available at first. By trial and error experiments, they have developed many of the basic formulas and techniques now used throughout the world.

Aside from engineering considerations, undoubtedly the British knew that recruitment of component and responsible people would be difficult and a flexible system of water distribution would lead to uncontrollable abuses. They were also concerned to keep operational costs at a minimum since they were interested in recovering their investment quickly. These considerations also underlay the policy of minimal local intervention; farmers were expected to build/maintain their watercourses and settle disputes among themselves.

4) Operational Spoils

The system of unlined channels (earthen canals) as established by the British suffered from substantial losses in the process of conveying water from rivers to farmgate; 25% of the total from the canal head to the outlet and another 15% from the outlet to the field. However, not all of these seepage losses are irretrievable and a substantial portion of this recharge is utilized against pumped irrigation. Nevertheless, these high water losses are a major impediment to boosting irrigation supplies for tail-enders and high consumtive use crops.

When this inefficiency and inflexibility (supply-driven nature) of the system is considered, together with the lack of an effective drainage network, then the causative factors invariably shift to weak O&M policies in vogue. Even though benefits accruing from O&M expenditure have been estimated to be high (i.e. a 30% increase in agricultural productivity in six years in response to a 10% increase in expenditure on canals in one year) Pakistan's canal system continues to deteriorate because of continuosly deferred maintenance. The maintenance in particular has become much more critical in lieu of virtually no enlargement or improvement of the canals to accommodate the post-Tarbela flows. The resulting overuns caused encroachment of the designed freeboard, erosion of the channel banks, and deformation of the cross sections.

5) Revenue Shortfalls

At the root of this problem lies the unrealistic charge for surface irrigation supplies that is far less than its opportunity cost (farm data suggests less than 5% of production input values). The irrigation canals were developed as a famine relief system, as well as a means of generating a significant amount of revenue. In fact, early canals were organized as stock companies with shares being sold and the revenue from the shares was expected to pay for the initial capital costs. The annual land payments were to go to the shareholders as return on their investment. Thus, there was a clear link between the provision of water and the resulting revenue from the irrigated lands.

Today, the situation is totally different. The revenue from the land tax does not come close to covering the actual costs of irrigation, nor does the revenue from the tax accrue to the irrigation departments. In relative terms, the land tax on a per hectare basis is much less today than it was when the irrigation canals were first instituted and, as a result, the gap between revenue and costs of systems operations continues to widen each year (from Rs. 578 million in 1980-81 to over Rs. 1 billion in 1983-84, from ACE 1989). This requires additional subsides each year from the GOP, to maintain the status quo.

The only attempts to recover costs of development directly have been in the charging of a double rate of *abiana* to farmers on the SCARP project areas and a reclamation charge in the early years of the SCARP operations. These charges nowhere near cover the cost of operating the SCARP projects (some twenty times the level of recovery), much less defray the development costs. Thus, the travails of the system are buttressed between the unbridgeable gap in O&M expenditures and the disregard for the efficient utilization of surface supplies as a scarce commodity.

B. The Agricultural Economy: Historical Gains

Pakistan's agricultural sector has had a historical annual growth rate of 3.7% and, in 1991-92, accounted for 66% of the value added contribution to GDP, with 49% coming from major crops (wheat, rice, cotton, maize and sugar cane) and 17% from minor crops (oilseeds and pulses) (IFAD report). Out of the total cultivated area of 21.4 million ha, 77% is irrigated and 23% is rainfed. In 1994-95, the total cropped areas amounted to 22.44 million ha of which food grains occupied 65% and cash crops 20%. About two-thirds of the wheat production increase during the last 15 years has come from improvements in yield and the balance from areal expansion; comparative figures for cotton and rice are 50% and 25%, respectively, while the yield increase for sugarcane has been much less. The expansion of cropped area has stagnated during the recent years because of continuing stress on the distribution of existing irrigation supplies beset with a low level of irrigation efficiency and structural incapacity for additional mobilization.

1) Resourcefulness in Production & Yields

Cropping patterns have changed over time; rice and wheat account for over 54% of the cropped area (an increase of over 10% since the late 1950s) while the area under sugarcane and cotton has also increased. The averages rates of growth in *production* of these four major crops between 1985-86 and 1990-91 have been fairly high (Figure 3(b)). The yield increases have been largest for wheat, followed by cotton and sugarcane, whereas the yield of rice is declining, reflecting increasing problems of water shortage, salinity and waterlogging in the irrigated areas. On the whole, average yields of almost all crops are low compared with international standards and the achievements of progressive farmers within the country. Given proper agronomic practices and use of inputs in a timely and proper proportion, average farm productivity can easily improve by 15-20%.

After the mid-1960s, with the introduction of the new high yielding disease resistant varieties, wheat production increased dramatically on both large and small farms. At present, almost all of the irrigated wheat is under high yielding varieties. In recent years, the growth in yield of this crop has been affected by a lack of varieties suitable for late planting in cotton/wheat and rice/wheat cycle areas. Also, at present, only 10% of the area is being sown with certified seed against a 20% required replacement rate. Between 1977-88, irrigated wheat yields increased at an annual growth rate of 1.9%, but World Bank data reveal that growth between 1984-88 stagnated, despite significant increases in farmgate water supplies (23%) and irrigated area (14%).

In the past, increases in wheat production in the Province of Punjab (major producer) came from three main sources: increase in cropping intensity; conversion of rainfed to irrigated areas; and use of high yielding varieties/fertilizer. However, it appears that these sources of growth would lose much of their significance in wake of promoting greater efficiency at all levels of inputs. When compared against the targeted growth rates of 4.45% for wheat and 4.07% for rice in the 6th Five Year Plan (1983-88), achievements were 0.43% and 1.19%, respectively. During the same period, the overall investment in the water sector was 17% below WAPDA's Revised Action Plan recommendations of 1979. Given the near levelling off of the availability of irrigation water per hectare of cultivated land, and evidence of a sharp decline in the marginal returns to further increases in the use of fertilizer, doubts begin to emerge about the ability to sustain current levels of productivity.

The production of cotton also has not been stable due to the absence of a long term price support policy, in addition to poor weather and pest attacks. The disastrous cotton failure in 1983-84 led to increased use of fertilizers and pesticides that subsequently increased

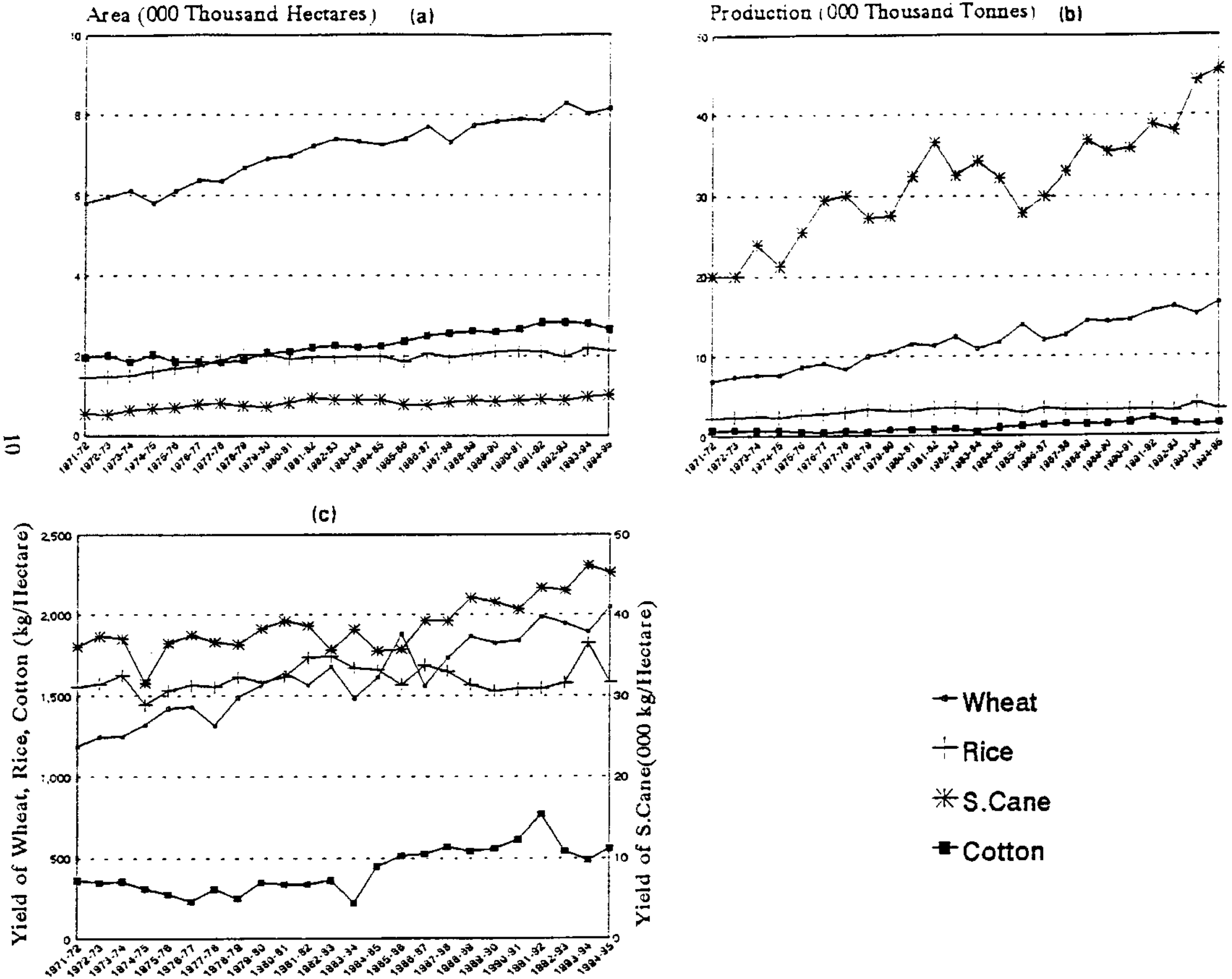


Figure 3 Historical Trends in Area, Production and Yield of Major Crops in Pakistan.

production from 5.9 million bales in 1984-85 to a record 12.82 million bales in 1991-92. The WSIP study ascribes the low crop yields primarily to low fertilizer use efficiency, inefficient on-farm water delivery and management, and inadequate transfer of available technology particularly to small-scale traditional farmers. However, these low yields per unit area mask, to some extent, the actual efficiency in using scarce irrigation water, which is relatively high among the better farmers.

The area sown to cereal crops in Pakistan is not expected to increase, and may actually diminish because of urban expansion, crop diversification and salinity. Yield gains, therefore, must compensate for any decline in area. According to CIMMYT, the international agricultural organization research devoted to wheat and maize developmenton, farm experiments suggest an economically recoverable yield gap for wheat of 1-1.5 t/ha, much less than the amount commonly cited by policy makers, but nevertheless significant. This is supported by IIMI's own studies relating to wheat yield per unit of water use (Bhatti, Schulze and Levine, 1991).

Nonetheless, there are still opportunities for raising wheat yields through further breeding and by improvements in husbandry, particularly on small farms. In fact, it is the smaller farms that are prone to higher cultivation intensities (over 85% under 5 ha of holding; Census of Agriculture, 1980). This is especially true for the labor intensive crops such as rice and sugarcane; however, the yield differences by farm size are relatively small with substantial scope for improvement.

In the future, there will be a need to focus on more efficient use of inputs rather than increased levels of inputs as the major source of growth. Hence, the best strategy is to look for widely appropriate system interventions such as deep tillage methods to conserve moisture in drier areas, a new fodder crop to relieve fodder constraints, a new cash crop suited to local conditions, or a new early maturing variety of a staple food crop to promote increased cropping intensity. In addition, these interventions will have to be evaluated for their impacts on the total farming system, since their effects are not just crop specific.

2) Irrigation Inputs

The total irrigation water supply at the *farmgate* has increased to about 15.79 Mhm, up from a mere 7.86 Mhm in 1965. The changes in the relative shares of surface and groundwater at the farmgate are also dramatic (Figure 4). Surface water (at farmgate) constituted about 86% of the total in 1965; however, now it is estimated to be about 64.55% (assuming a groundwater contribution in 1996 at 5.6Mhm or 45.4 MAF). The lions share in the increased groundwater pumpage goes to the private tubewell development which was minimal in the initial stages of development of this resource (Figure 5). Over the years, continued pumpage from higher salt bearing strata have introduced and accelerated the process of secondary salinization in the root zone that has adversely affected crop yields;

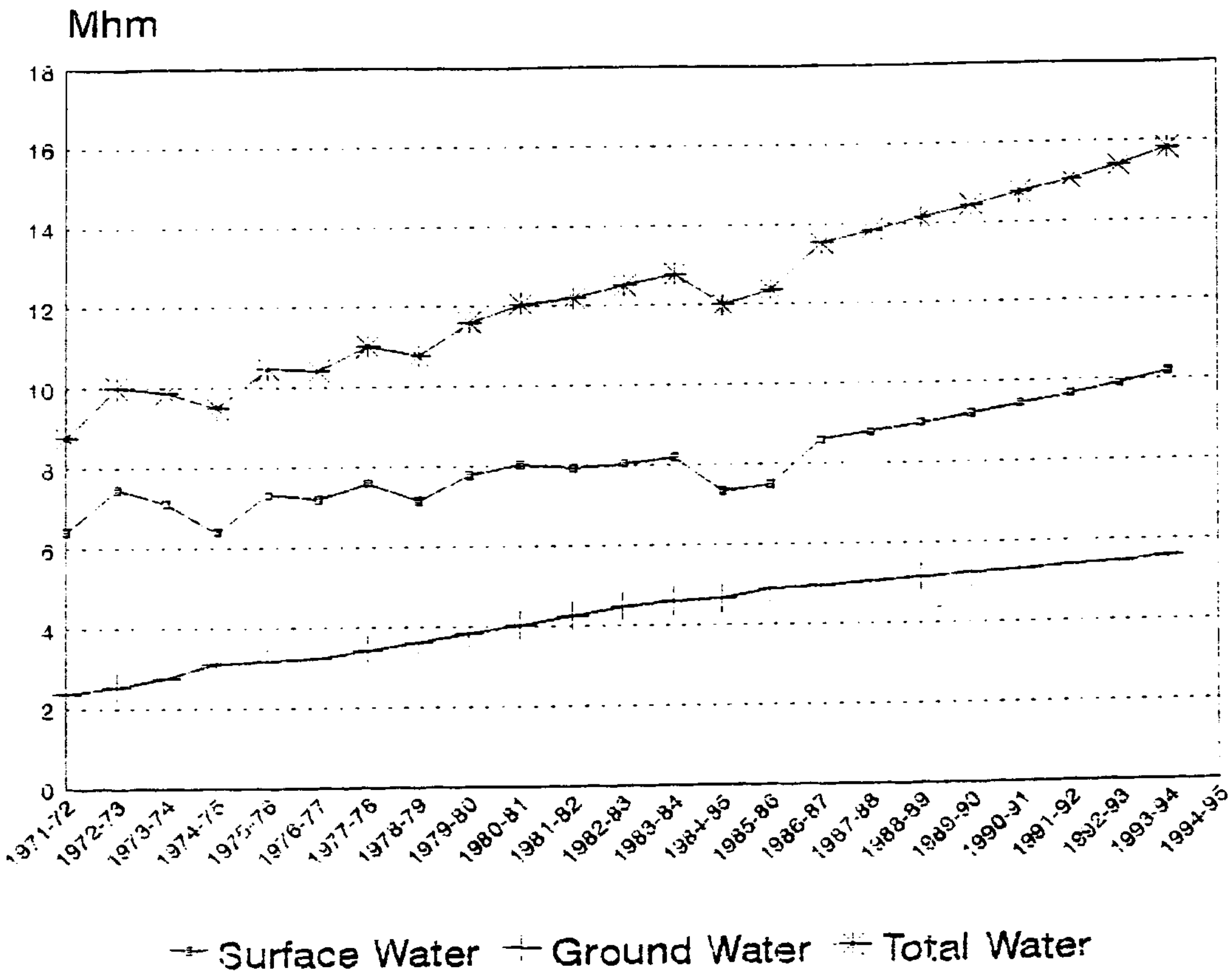
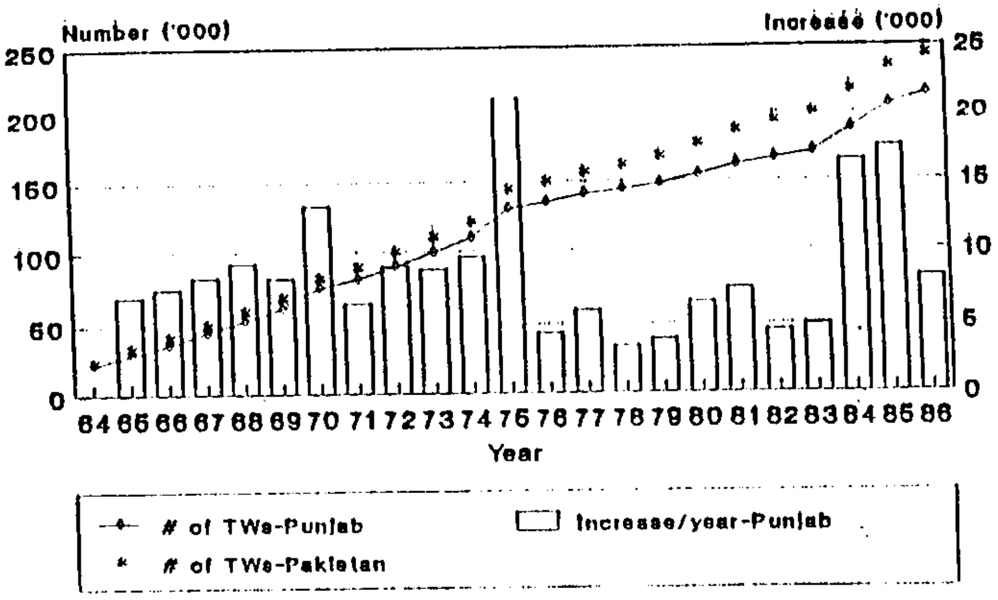
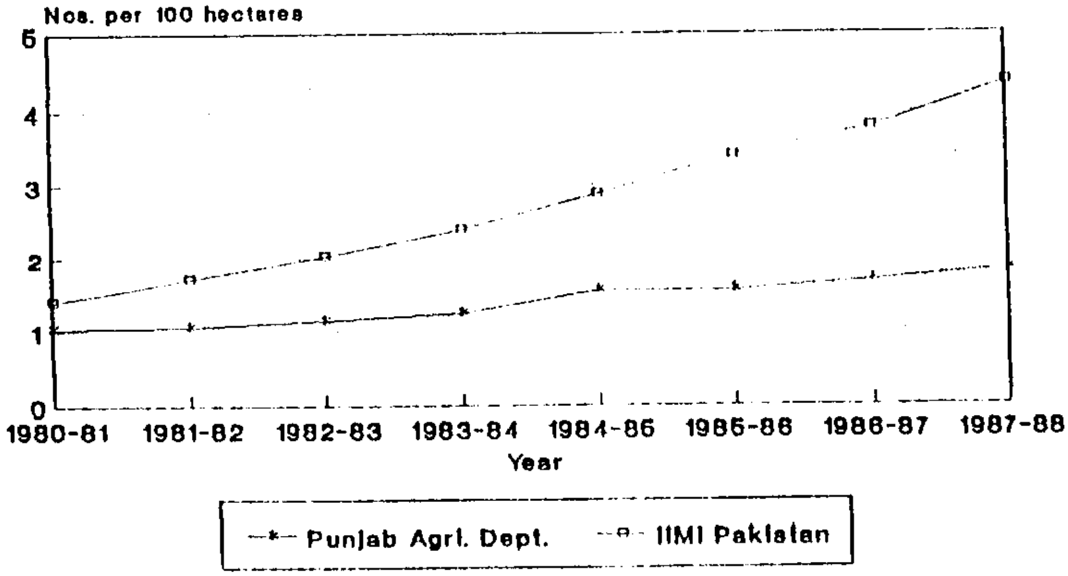


Figure 4 Average of Irrigation Supplies at the Farmgate.



Source: WAPDA, 1988

Figure 5(a) Private Tubewell Development in Pakistan and Punjab.



IIMI - Farooqabad SD Canal Watercourses
PAD - Sheikhupura District

Figure 5(b) Densities of Private Tubewells; Punjab Agriculture Department vs IIMI Data.

however, this increase in pumpage has also repressed the rising watertables that had previously responded to higher irrigation related recharges during the Kharif season.

The rate of growth of groundwater contributions to the total irrigation supplies has also tapered off due to the reduction in the number of operative public tubewells, as well as the decline in the specific capacity of the private tubewells. In a supply driven irrigation system, this assumes critical proportions with respect to the already rigid availability of surface supplies for crop water requirements.

C. Threats to Sustainability

The impressive expansion in the availability of land in the first three decades of Pakistan began to falter from the late eighties onwards. The *area* sown to important crops has seen minimum increase (Figure 3(a)). In comparison to the last population census growth rate of 3.1%, the annual rates of increase in the cultivable and cropped areas have been under 1%. It is well worth considering that population density per square kilometer of cropped area has already increased from 26.25 in 1951 to 51.2 in 1989, a rise of about 95%, despite substantial expansion in cropped area. At the same time, according to agricultural censuses, the total number of farms in the country increased from 3.762 million in 1972 to over 44 million in 1980, with a corresponding decrease in farm size from 5.27 ha to 4.68 ha; in other words, the land fragmentation has increasingly rendered the farm holdings uneconomic.

1) Projecting the Shortfalls

The foregoing reinforces what has been described by the WSIP study (1990) as of unthinkable consequence given the growing gap between burgeoning population and the stagnant yields of major crops. The propositions entailed in the WSIPS specified strategic choices towards major investments across the water sector. Improved criteria and procedures for screening projects have also been proposed and both elements constitute the contest for a medium term (1990-2000) investment plan for the sector. The planning for the investment portfolio necessitated the creation of a new infrastructure of Provincial Planning Cells to rationalize investment strategies concordant with evolving priorities. The catalyst to all the propositions therein is the imminent necessity for sharp increases in agricultural productivity to meet the deficits predicted for the year 2000 and onwards to 2012-13. Constraints pertinent to this realization could be grouped under three categories---physical, institutional, and financial, with water availability providing the underpinnings to all of the three. Projects aimed at increased crop production (whether from growth in irrigated area, extra water or increased water delivery effciency) formed 20% of the portfolio. Infrastructural improvements such as canal repairs and storage provisions accounted for 40% of projects, while 35% were directed toward protection of crops from waterlogging and salinity. The remainng 5% were aimed at multiple use of rice fields by removing excess water and boosting the rate of soil drying for subsequent crop.

The National Commission on Agriculture (NCA) Report (1988) estimates that the present rate of agricultural growth must rise by an average of 5% per annum (4% for crops) to keep up with the population demand. This is still too conservative of an estimate as it has been projected for a population of 140 million by the year 2000 instead of the 148 million by the Planning Commission. It is also very optimistic considering the historical *yield* increases since 1971-72 (Figure 3(c)). Except for cotton which experienced a high rate of yield increase ***over the past decade***, the rate of annual yield growth of all other crops has been about 2% or less. It is not possible to say how much of the yield increase has resulted from increased water supply per irrigated hectare over the period, which on the average was about 7% (WSIP, 1990)(2.4% when comparing for 1965-88).

Assuming the NCA projections on *yields* are achieved through 1999-2000, and the rate of increase sustained thereafter to 2012-13, the increase in irrigated crop area necessary for this purpose would be 1.8 Mha over the 1987-88 level and the additional irrigation water requirement would be 1.35 Mhm (11 MAF) during Kharif and 1.2 Mhm (9.7 MAF) during Rabi. For the "with" and "without" scenarios on water sector investments, the increase in crop-specific irrigation water supplies is given in Table 1. They are based on current levels of application which are less than optimal from the standpoint of high yields. Also, the requirements at the farmgate assume 71% conveyance efficiency which is higher than observed on many watercourses. In comparison to the 1986-87 figures on farmgate deliveries, the cumulative increase in water for the "with" and "without" investment scenarios are given in Table 2.

The NCA projections on crop *production* for "with" and "without" water sector investments are presented in Table 3, and it is here that the doubts begin to appear about the attainment of these objectives without continued water sector investments to minimize land deterioration, increase in water supplies per cropped hectare, or at least to improve the timeliness of water deliveries for consumptive use. Actually, without future investments, the yield increases projected as such are also questionable in lieu of the persistent waterlogging and salinity hazard in many areas. The figures from the Planning Commission (1988) are only slightly higher (Table 4) but compare only the wheat and rice crops.

2) Land Degradation

As stated earlier, the continued accumulation of salts in the soil strata is a major threat to the sustainability of irrigated agriculture in Pakistan (Table 5). In the Lower Indus plain, the salts can be disposed off into the sea. A billion dollar project (Left Bank Outfall Drain) is being constructed to accelerate discharges into the sea. In the Upper Indus plain, the drainage effluent is used locally by mixing it with canal supplies, disposed off into rivers or into evaporation ponds. This has a negative effect on the environment. Disposal in canals and rivers simply shifts the salinity hazards to downstream users, whereas the local users' drainage effluent results in the recirculation of salts in the system and a build up of higher concentrations of salt in the top soil.

Table 1. Additional Irrigation Water Requirements at the Farmgate (Mhm) (Farmgate Efficiency 71%).

Crop	No Water Sector Investment		With Water Sector Investment	
	1999-2000	2012-13	1999-2000	2012-13
Wheat	0.421	1.715	0.222	0.097
Rice	0.832	2.88	0.778	0.139
Sugarcane	0.56	1.212	0.165	0.036
Cotton	0.24	1.062	0.042	-

Source: WSIP, 1990

Table 2. Increase in Farmgate Delivery (%age).

Year	Season	No Investment	With Investment
1999-200	Kharif	27.8	17.1
	Rabi	29.7	21.3
2012-13	Kharif	81.8	6.3
	Rabi	79.7	16.6

Source: WSIP, 1990

Table 3. Projected Crop Production (000 tonnes).

Crop	No Water Sector Investment			With Water Sector Investment		
	1997-98	1999-2000	2012-13	** Achievement of NCA targets in yield and export		
				1997-98	1999-2000	2012-13
Wheat	14774	15211	18390	17876	18964	27850
Rice	3409	3454	3772	4313	4580	6882
Sugarcane	33011	33209	34528	40007	41950	57100
Cotton (Lint)	1603	1652	2004	5212*	5508*	7887*

* Seed Cotton
** Assuming 2.5% Population Growth
Source: WSIP, 1990

Table 4. Projected Crop Production (000 tones).

Crop	Years				
	1997-98	1999-2000	2002-03	2007-08	2012-13
Wheat	19036	20398	22580	25722	28781
Rice	3242	3467	3839	4373	4893

Source: Planning Commission, Seventh Five Year Plan (1988-93) and Perspective Plan, 1988-2003

Table 5. Estimated Salt Load in the Surface (a) and Groundwater (b) Irrigation Supplies (Punjab).

(a)

Zones	Area (Mha)	Canal (Mhm)	Inflow (ppm)	Salts	
				(Mt)	(t/ha/yr)
Fresh GroundWater	7.6405	5.1292	200	11.31	1.5814
Saline GroundWater	2.0275	1.5190	200	3.35	1.7297

(b)

Area	Pumpage (Mhm)	App. Quality (ppm)	Salts	
			(Mt)	(t/ha)
Public	0.8261	750	6.8	0.8895
Private	2.7002	600	17.9	2.3474

Source: Planning Division, Nov. 1988

Table 6. Temporal Comparison of Surface Salinity in the Punjab Province, Pakistan.

(a)

Survey Period	Area (000 ha)	Surface Salinity (%age of Aerial Coverage)				
		Salt Free	Slightly Saline	Moderately Saline	Strongly Saline	Miscellaneous
1977-79	10172.5	84	7	4	3	2
1953-65		72	15	5	6	2

(b). Temporal Comparison of Profile Salinity in the Punjab Province, Pakistan

Survey Period	Total Profile	Profile Salinity (%age of Profile Samples)				
		Non-Saline Non-Sodic	Saline	Saline Sodic	Non-Saline Sodic	Missing Data
1977-79	39963	73	7	14	5	1
1962-65	23662	55	6	27	11	1

Source: Soil Salinity Survey Data, S & R Organization, Planning Division, WAPDA, 1981

Past studies on top soil degradation focused on physical damage to the soil; the researchers did not quantify the economic cost, nor the potential benefits of changes in public policies. A comprehensive review of the soil salinity research conducted within the country by Niazi et. al. (1990) revealed a large body of information that not only remains untapped by the planners and researchers but also controversial in many respects, in terms of extent-wise reporting. Also, no differentiation appears between fossil (naturally occurring) and accelerated (being created due to brackish water irrigation and non-scientific management practices) salinity. That a significant portion of the research was carried out in laboratories with low adoptability and reproduceabilty (e.g. salt tolerance studies) and that the reclamation techniques lacked site specific technology have been additional stumbling blocks towards an integrated approach to salinity management.

Public sector undertakings at the national level to assess the magnitude of both surface and profile salinity have been far in between, and, depending upon the agency involved, difficult to correlate. The Indus Basin salinity survey by WAPDA during 1977-79 provides comparative figures with the earliest investigations dating back to the mid-fifties. In reference to the Punjab province, the comparison of both surface and profile salinity is given in Table 6. Aside from the intervening changes in the qualitative extent of salinity across more than two decades of reference and adequacy of sampling, the indications are that soil salinity is dissipating across all levels of classification. Since no integrated assessments on soil salinization have been made beyond the 1977-79 Revised Action Program (RAP) survey by WAPDA, it is possible that these figures are no longer a potent reference of changes to soil salinization. In fact, in the period since then, there has been an increase of nearly 55% in groundwater pumpage with salt loads anywhere between 0.89-2.34 tons/ha/year (Table 5). This is in addition to the salts already being added via surface irrigation. While the estimates on the quantum of salts retained in the root zone may most likely be conjecture, the broader reliance on soil chemistry would dictate a situation that would threaten the gains made through soil reclamation in the past.

In addition to salinity, the root zone suffocation caused by high watertables across the irrigated landscape has been a persistent problem, though not as acute as in the past. In fact, the past reclamation schemes had removal of high watertables as their primary objective. The GoP continues to reckon that deep watertables < 1 meter in irrigated regimes as disaster areas requiring concentrated efforts. In the past, high watertables were considered to be a direct contributor of salt accumulation in the root zone (through capillary action); however, this notion no longer holds sway as a 'twin menace'.

3) Recourse to Reclamation

Pakistan has heavily invested in physical solutions to remedy its existing waterlogging and salinity problems, like the Salinity Control and Reclamation Projects (SCARPs) initiated since the 1960s. Although more than US $450 million have so far been invested upto 1990 in 44 SCARP Projects covering 5.17 Mha, its performance has been uneven; initial success was followed by a decline in the expected benefits. Intrusion of saline groundwater often resulted in the closure of TWs, since its quality prevented further use for irrigation purposes. Moreover, the decrease in the pumpage capacity of the wells, on average 5% per annum, necessitated replacement in some cases within 8 years of original installation; this put the O&M costs at a premium (revenue receipts from reclamation cess were only 20% of the annual O&M). Underfunding of these requirements resulted in further deterioration in the performance of the SCARPs.

Subsurface (tile) drainage projects have also faced problems in the construction and operational aspects, like inadequate gravel envelopes, difficulty in proper backfilling resulting in the development of sinkholes, and siltation of pipes. Some pipes silted so badly that they had to be replaced by new lines. Fine sand fractions in the water had a disastrous effect on the bearings of the pumps, which became non-functional in a short time. The economics of the subsurface drainage require capacities to be kept to the minimum; over design, as in parts of the Fourth Drainage Project in the Rechna Doab, is not affordable unless increased flows can be guaranteed for translation into drainage benefits. With the current inequalities of the irrigation system, this becomes too site-specific. Besides, increased drainage flows captured by the laterals into rivers and canals only increase the salinity for the downstream user. Given the very low volume of irrigation supplies available to the farmers, even marginal levels of salinity could build up to larger concentrations in the overall disposal through sumps. Irrigation practices would have to change to achieve the dilution, meaning significantly more water per unit area of crop (thus reducing the cropped area) or supplying more water at the farmgate, either of which is difficult to achieve at present. The problem is not just maintaining a salt balance in the root zone, but disposal of the additional salinity picked up from the huge reservoir of salt through which drainage flows pass, especially subsurface drainage flows.

It is too early to determine the sustainability problems for the tile drainage projects in the long run because no regular monitoring is being carried out. The indications, however, are that like tubewells the useful life for tile drainage projects may also be much less than planned. This would adversely affect its economic justification that is closely tied to cultivation intensities of high value cropping systems on a sustainable basis.

4) Sharing the Management

Starting with the Sixth Five Year Plan of the GoP (1983-87), the SCARP Transition Program aimed to relinquish control of the tubewells operating in the fresh groundwater (FGW) regime to the farmers, thereby limiting the O&M expenditures to saline tubewell drainage schemes only. No further tubewell drainage schemes have been planned for the fresh water zones.

According to the second phase of the SCARP-I Transition Pilot Project (1992-93 to 1997-98), out of the 1870 tubewells, 1346 were to be closed. Out of these closed ones, 1010 were to be replaced by 13,000 private T/Ws and 336 targeted for transfer to interested farmers. The remaining 524 T/Ws were to be retained on account of brackish pumpage.

Unfortunately, unlike transitional schemes for reclamation tubewells in the FGW areas, the burden of responsibility for the O&M of saline groundwater (SGW) tubewells along with the surface and tile drainage schemes cannot be offloaded. Consequently, the planned and throwforward expenditures under the Eighth Five Year Plan continue to reflect the liabilities of the Federal Government in this respect (Table 7).

D. Threat Perception in Retrospect

There is considerable controversy over the actual extent and modern trend of waterlogging and salinity. Two factors are responsible for the controversy: first, the relevant information is inadequate, inconsistent, and subject to different interpretations; second, large capital and O&M costs has politicized the issue. Studies during the 1960s (Revelle report, Whitehouse 1964: Lieftinck et.al. 1969) suggested that 20,000-40,000 ha were going out of production annually from waterlogging and salinity. In the late 1970s, some authorities claimed as much as 50% of the canal irrigated areas of the country had a watertable of less than 3 m and was thus waterlogged or potentially waterlogged, and as much as a third of the country's irrigated land was strongly saline or sodic (Malik, 1978; Lowdermilk et al. 1978). According to data published by Hussain (1970) and Rafiq (1975), never more than 0.6% of the CCA was severely waterlogged in Pakistan. There are very small areas, not more than 0.4 Mha, in the Indus plains where crop yields are affected by a perched watertable. Of this, only a small proportion is severely affected. Likewise, surveys conducted by different public agencies have shown a decreasing trend in the area of affectation (Tables 6, 8, & 9).

In tandem with these periodic surveys, the framework for organized research into the alleviation of land degradation was also established by the public sector agencies (e.g. the Soil Survey followed by WAPDA). Since the scope of operations launched by WAPDA was the most extensive in the country, its contributions to this effect over the years have spawned several agencies like MONA Reclamation Experimental Project, SCARP Monitoring Org., IWASRI, Lower Indus Water Management, and Soils and Reclamation Directorate. However, in the last couple of decades, this contribution has become much more focused due to a host of premier research institutions working within the country, including PARC, PCRWR, DRIP, and agriculture universities. Routine breeding of new varieties of major crops is the most common research activity in agriculture; however due to a lack of coordination, there is duplication and the effectiveness of Pakistan's considerable research effort is dissipated. There is a need for focused research pertaining to the following:

- Micro-nutrient deficiencies leading to yield decline;
- Establish location-specific on-farm research programs for all major crops to develop site-specific recommendations;

Table 7. Rechna Doab: Projects with Financial Allocations (Eighth Five Year Plan, 1993-98)(at 1993-94 Prices).

Name of Project	Total Cost (m.Rs.)	Expenditure upto June, 1993	Throwforward for 8th Plan	1993-94	1994-95	1995-96	1996-97	1997-98	Total	Throwforward
Drainage-IV	1590	1497	93	179	-	-	-	-	179	0
Gojra Khewra-II	589	444	133	29	47	57	-	-	133	0
Shorkot Kamalia (SGW)	268	180	88	29	59	-	-	-	80	0
Upper Rechna Remaining	231	148	83	37	46	-	-	-	83	0
Upper Rechna-II (Remaining)	2000	-	-	-	-	125	150	180	455	1545
Drainage-IV (Remaining)	435	-	-	-	-	100	150	185	435	0

Table 8. Extent of Salt Affected and Waterlogged Soils (Pakistan) as reported by DLR.

Year	Total Area Surveyed (Mha)	Salt Affected Area		Waterlogged Area	
		Mha	Percent	Thousand ha	Percent
1961-62	14.038	2.132	15.12	33.994	0.24
1962-63	15.252	2.270	14.90	79.319	0.52
1964-65	14.961	2.201	14.70	100.767	0.67
1966-67	15.163	2.214	14.90	79.723	0.57
1967-68	15.402	2.214	14.30	84.580	0.55

Table 9. Extent and Categories of Salt Affected Soils and their Analysis as Reported by SSoP (1967-79) (000 ha).

	Saline	Saline Sodic		Sodic	Total	Gypsiferous Saline Sodic
		Permeable	Impermeable			
Punjab (%)	504.4	1225.3	856.5	-	2586.2	57.2
	19.5	47.4	33.1	-	100.0	2.2

- Develop early maturing varieties for increased turnaround time in harvest (this would minimize labor displacement and reduce capital overlays on machinary);
- Applicability of zero tillage to shorten turnaround time from one crop to the next and to reduce land preparation costs;
- Develop more compatible cropping patterns, like the adoption of sunflowers in the Punjab rice-wheat zone at the expense of late planted wheat;
- Develop varieties suitable for late planting (in the irrigated areas, where double cropping is now the norm, close to two-thirds of the wheat is planted late after cotton, rice, and sugarcane).

The GOP's Eighth Five Year Plan (1993-1998) anticipates the overall increase in irrigation water availability from 125.12 MAF (15.43 Mhm) to 133.28 MAF (16.44 Mhm). Coincident with this increase in farmgate availability of water is the expected increase in *cropped* area by 0.69 Mha. Much of this increase is to be realized from within the existing gross commanded area plagued with high watertables. With a 50% utilization rate assumed for the existing SCARP TWs with no increase or decrease in pumpage up to 1998, and an increase in private tubewells at the rate of 6000/yr with almost equal pumpage in both Kharif and Rabi seasons (20% utilization rate), the overall contributions from groundwater comes to over 6.28 Mhm by the end of the Plan. This in essence is a continuation of the policies adopted under the Sixth Plan referred to earlier in that;

- ongoing SCARP schemes are to be given priority;
- vertical drainage in FGW zones are to be controlled by the private sector as before, except in difficult aquifer conditions;
- areas not severely waterlogged are to be tackled by using preventive measures such as:

    i. deliver only needed supplies of water;
    ii. provide proper grading to lands; and
    iii. changeover to extensive Rabi cultivation;

- transition of public tubewells in FGW areas to continue; and
- gradual replacement of deteriorated SCARP TWs.

The Plan, however, has not identified the need for monitoring of the SCARP transition process to ascertain the long term effects, including:

- replaced volume of pumpage through private wells;

- net effect on depth to watertable; and
- change in tubewell commanded area and impact on cropping intensities.

In addition to the above SCARP related targets, the Plan forsees the benefits in irrigation water savings accruing from the ongoing On-Farm Water Management (OFWM) program (see details below); lining of 10,000 watercourses has been anticipated to coincide with precision land leveling of 55,000 ha of farmland.

E. The Social Dimension

During the 1970s, when the Govt. became very concerned about alleged mismanagement of water by farmers at the watercourse level, a new organization, the On-Farm Water Management Directorate (OFWMD), was established within the provincial agriculture departments (PADs) to take the lead in inducing farmers to rehabilitate watercourses and do precision land leveling. Financed by the USAID between 1976 and 1981, the project was the earliest attempt in Pakistan to introduce Water Users Associations (WUAs) among farmers of irrigated lands. New legislation was adopted in each province, ostensibly enabling the establishment of water users associations but in fact strengthening the power of the state over the watercourses. Farmers were required to carry out maintenance themselves or repay the costs (25% in 10 installments) if the government does it for them. The whole package had a predetermined civil works orientation that paid scant attention to social organization. It was based on the premise that the government required farmers labor contribution or cash for renovation and maintenance of watercourses and that farmers should undertake O&M of lined watercourses. It was natural that farmers avoided WUAs when the chief function of the WUAs were to organize farmers free labor and cash for OFWM activities.

More recently, under the Command Water Management (CWM) Project, for which a preliminary evaluation conducted by the CWM directorate indicate an average increase of 8% in cropping intensity, there was an attempt to integrate institutions responsible for fertilizer/seed supply, extension, watercourse reconstruction, and the Irrigation Department itself. CWM was presented ostensibly as a decentralization project which attempts to develop a degree of self-management at a localized level. There was a provision for farmer participation in this program but similar to the OFWM program, such participation is based on the legislation described above, which defines a long list of duties and sanctions which the government can impose on associations not carrying out required maintenance. Government officials retain control of water and other resources and continue to respond to directives from the provincial capital rather than to the demands of local farmers. All of these activities are directed at trying to impose state wishes at the local level, but they do not address the fundamental organization issues in Pakistan's irrigation management structure, which fails to recognize the social dimension of the problem.

III. PUBLIC SECTOR INITIATIVES AT LAND REHABILITATION

A. The Post-Independence Appraisal

The Pakistan Government, in 1949-50, requested the Food and Agriculture Organization (FAO) of the United Nations to find a solution to the waterlogging and salinity problem. A report published by the FAO irrigation and drainage experts emphasized further investigations into excess soil water, sources of salts/alkali and their effects on productivity of soils, leaching requirements, and methods of drainage. For the installation of tile drains, the report suggested only pilot studies in areas where soils were suitable. This was to allow quantification of irrigation and drainage water requirements.

Carlston (1953) in his report to FAO suggested that the seepage from the existing canals was the major cause of the rise in levels of groundwater. For draining waterlogged areas, either tile drains or tubewells were recommended; tubewells could be located on lands requiring drainage, provided the water to be pumped was suitable for irrigation. Eaton (1965) also warned against the exploitation of the groundwater resource from poor quality strata without adequate safeguards.

Another report published by the FAO (Olafson, 1955) examined the water bearing characteristics, water quality, and pumping of groundwater within Rechna Doab. The use of gypsum and dilution of tubewell water with canal water was recommended. The report cited that high canal seepage should be counteracted by excessive pumping to help lower the groundwater levels.

B. Administrative Framework

Following conclusive realizations pertaining to the deleterious effects of poor groundwater quality regimen on surface and profile salinization, the GoP established the Water and Soils Investigation Division (WASID) in 1954 (initially the Groundwater Development Organization) through the assistance of the predecessor to USAID. The mandate for this purpose was derived from a scientific determination of:

- the physical characteristics, distribution and continuity of the soils and water bearing material through soil surveys, land classification, surface and sub-surface geology;
- the distribution and chemical character of all waters;
- the safe yield in areas should be compatible with the economy of drainage, irrigation, and reclamation programs by pumping from tubewells; and
- the extent of saline/alkaline lands and groundwater aquifers.

The results of WASID investigations were utilized by its successor organization, the Water and Power Development Authority (WAPDA) established in 1958 towards the implementation of nation-wide reclamation programs. In May 1961, WAPDA published a report titled "Program for Waterlogging and Salinity Control in Irrigated Areas of West Pakistan." It contained a ten year program of waterlogging and salinity control measures through the development of groundwater resources. The entire program of Salinity Control and Reclamation Projects (SCARPs) was estimated to require about 31,500 tubewells (28,000 for irrigation and 3,500 for drainage), over 12,000 kms of major surface drainage channels and 40,000 kms of supplementary drains. The total cost was estimated at Rs. 5.9 billion (approximate exchange rate was USD 1=Rupees 4). The objectives of SCARPS were as under:

- Increase irrigation water supply through development of ground water resources and also achieve associated sub-surface drainage;
- Reclamation and control of saline soils; and
- Foment rapid agricultural growth by increasing the cropping intensity to 150 percent;

The experience to date from these SCARPs has not been encouraging as the accomplishments fell short of the strategic gains over the long term. The reasons to this effect have already been provided under the section on Threats to Sustainability.

The program was periodically reviewed and reshaped and a series of reports were produced for the guidance of the Government of Pakistan. The last of these reports was the Revised Action Program for Irrigated Agriculture published in May 1979 by the Master Planning and Review Division of WAPDA. Its role towards reshaping of the reclamation strategy is discussed below.

C. Major Policy Reviews

Meanwhile, keeping in view the magnitude of the problem, the GoP realized that though the subject of reclamation was a provincial responsibility it required a national effort to eradicate waterlogging and salinity. With the concurrence of the provinces, it was resolved that the Federal Government should take over the responsibility for drainage and reclamation of agriculture land. In view of the above, the Planning and Development Division of the Federal Government, in consultation with WAPDA and the provincial governments, prepared an "Accelerated Program of Waterlogging and Salinity Control" in 1973 towards reclamation of 5.67 Mha by 1985. It provided for the construction of tubewells (to lower the watertable) and surface drains for storm water runoff and disposal of saline effluent. This program served as the basis for the preparation of a comprehensive plan for the entire irrigated area of the country. It was to be an update to an earler Action Program developed in 1967 by the World Bank.

Under an agreement with the UNDP in 1975, the plan preparation was assigned to WAPDA with the advisory technical assistance from Harza Engineering Company, International. The primary objective was to provide a sound basis for long term planning and implementation of the government's investment program in irrigation, drainage, soil reclamation, and flood protection. It recognised the deficiencies in the past policies with respect to water availability at the farm level and concurrent decision-making on production and investments by the farmers. This lack of control was sought to be alleviated through investments in private tubewell development in usable groundwater areas and gradual replacement of the existing public tubewells (in addition to basin-wide management of surface supplies).

The plan proposed the following main strategies to address the waterlogging and salinity problems:

- all future development of usable groundwater should be entrusted to the private sector, but with the assistance of the public sector in the form of supervised credit, technology supply and information; and

- present SCARP tubewells in usable groundwater areas should be gradually phased out and replaced by private tubewells.

The above formed the basis for the launch of the RAP; the policy of privatisation of usable groundwater was principally accepted by the National Board and recommended for implementation in the following Sixth Five Year Plan of the GoP (1983-87) that stressed the following:

- Instead of reclaiming large gross command areas, emphasis should be given to the "disastrous areas" where the watertable was within 1.5 meters in April/June;

- The on-going projects in the fresh groundwater (FGW) zones should be completed as originally conceived;

- Priority should be given to the areas underlain by saline ground waters (SGW) on the basis of productivity of land, types of crops grown, density of population and rate of rise of the watertable; and

- The reclamation of the FGW zone where cultivation of crops is possible should be left to the private sector, which the private sector should be encouraged to install tubewells by providing a closely spaced electric grid, loans, and tubewell subsidies.

IV. RESEARCH MANDATE: BUILDING THE MOMENTUM

A. The Systems Approach

Under the Irrigation System Management/Rehabilitation (ISM/R) Project which started in 1983, USAID provided U.S $110 m for the rehabilitation of canals/drains, improvement of the infrastructure, and development of new water management technologies. One-fourth of the assistance went to supporting and strengthening the Pakistan research institutions working in irrigation or in closely related fields. A technical advisory group from the University of Idaho assisted the implementing agencies of the GOP in design and initial implementation of this project. The Project was an effort aimed at addressing the urgent need to initiate adaptive research programs to investigate the issues associated with the planing, design, implementation and management of water in agricultural development.

After the departure of the University of Idaho team during late 1990, IIMI's country program in Pakistan provided the technical support. IIMI agreed to assist the Government of Pakistan research organizations in selected priority research programs for the enhancement of their research capacity and in the dissemination of their research findings. IIMI's main role was to provide coordinated technical assistance to those institutes that were mostly in the final phase of completing various irrigation research activities initiated under the project. Exceptions were the PARC subproject on improving efficiency of on-farm water use and application, phase II of the PCRWR subproject in encouraging water users for better water management, and Sindh Irrigation Department studies on physical hydraulic modeling of irrigation outlets, sediment excluders/ejectors, etc.

As the lead agency in water resources development, WAPDA's contribution within the ISMR was implemented over a seven year period from July 1986 to June 1993 and covered the following (Munir, 1993):

1. Integrated watercourse management;
2. Farm water management;
3. Beyond watercourse improvement;
4. Irrigation systems outside the Indus Basin;
5. Public and private tubewells performances; and
6. Ground- and surface water models.

The research, conducted under actual field condition and in association with the farmers, introduced a new found emphasis on irrigation management as an important cornerstone to project development across multiple levels of the irrigation system.

B. Farm Level Diagnostics

Past investments into the augmentation of the surface supplies at the farmgate had assumed water losses below the outlet to be minimal and due mostly to evapotranspiration. It was thought most of the water consumed by plants from the root zone, rahter than realizing that water losses below the mogha were subsequently contributing to ground water recharge.

In the early 1970s research teams from Colorado State University, in cooperation with Pakistani organizations, especially the Mona Reclamation Experimental Project (supported by the funding from United States Agency for International Development), began exploring causes of land deterioration at the farm level. They started by measuring watercourse and field application efficiencies that on the whole were shown to be substantially greater than had previously been assumed. Overall, delivery efficiency of 60% or less within the watercourse was further compromised by wasteful irrigation practices stemming from a lack of knowledge about soil-plant-water relationships. In the years to come, these findings became the harbinger of the OFWM and CWM projects that were designed to improve the efficiency of water delivery and usage below the outlet.

Whereas detailed measurements have been taken on the existing physical system, its implications for system level management require an understanding of water distribution on either side of the mogha divide. The main findings of farm level irrigation management research, in part sponsored by IFAD, are as follows:

- High marginal yields per unit of water applied appear to be the main objective of the farmers rather than gains per unit of land;
- Variability and unreliability appear to be key obstacles in improving water use efficiency at the farm;
- Increasingly, groundwater of relatively poor quality is being used to compensate for these inadequate and unreliable surface supplies;
- Amounts applied in individual irrigation events vary greatly and are often higher than required, reducing water use efficiency; and
- Irrigation practices differ greatly, even within the same soil, water supply, and crop conditions, which reflects on the efficiency of onfarm water use.

C. Regulatory Reforms

IIMI studies of water distribution in the surface water systems indicates periods of surplus supplies that coincide with harvest and land preparation. The magnitude of this surplus varies both temporally and spatially. It has been difficult to utilize this water for productive purposes, particularly for leaching salts from the soil profile because the present degree of control, both physical and regulatory, at the main, distributary and watercourse levels restricts allocation flexibility for this purpose. Besides, while the farmers suffer from lack of understanding of the utility of leaching, the Irrigation Department has been slow to react to its potential benefits.

In recent times, results from a study conducted by IIMI (Bandaragoda and Rehman, 1994) of the reclamation operations of the DLR in the Upper and Lower Gugera and Burala Branches of the LCC system during Kharif of 1992 showed that:

- though intended for salinized lands, reclamation operations are conducted on all types of land;
- irrigation supplies intended for reclamation are not being used accordingly, it is reckoned to be a cheap augmentation of the normal supplies;
- the process of selecting land for reclamation is subjective and not strictly related to the salinity status of the lands;
- the PID reclamatin shoots plan are different from those develped by the DLR;
- reclamation shoots are generally provided in the head reaches of the channels, which impacts adversely on the water distribution equity, thereby causing a greater occurrance of irrigation-induced salinty at tail areas; and
- the farmers are in favor of reclamation shoots due to their positive effect on lands and crop production.

DLR data on LCC East Circle also indicates that the reclamation coverage in recent years has dropped (Table 10). In Kharif 1992, the saline area selected for reclamation supplies was only about 0.5% of the total CCA, and out of this only 59% was under rice, which is one of the recommended reclamation crops for Kharif season (Bandaragoda, 1994). The low percentage of area under rice confirms the farmers' comments (during field interviews by IIMI) that DLR's reclamation operations are not planned and initiated in time for them to start the rice cultivation. The data also indicates a decrease in the available reclamation supplies, which can partly be attributed to the canal maintenance, and the rest to the increase in the demand itself.

The provision of extra supplies for leaching purposes is operationally adequate, especially for rice (Figures 6 & 7). However, the notion that reclamation shoots are based on additional water supplies, over and above the channel regulations, has not been substantiated by IIMI observations for six distributaries in the LCC East Circle during Kharif 1992 (Table 11)(Bandaragoda and Rehman, 1994). This resulted in a further decline in the irrigation supplies at the tails of all the channels studied; not surprisingly, none of the

Table 10. Reclamation activities in the LCC East Circle (1985-86 to 1991-1992).

Year	Total *Thur* area (acres)	Reclamation discharge demanded (cfs)	Reclamation discharge sanctioned (cfs)	Reclamation discharge actually utilized (cfs)	Area operated (acres)	Area declared reclaimed during the year (acres)
1985-86	261,614	319.24	117.55	114.16	5,282	2,595
1986-87	255,102	300.50	162.55	159.34	7,187	1,637
1987-88	263,680	317.04	184.44	174.00	8,118	889
1988-89	263,638	332.17	174.19	159.36	7,213	1,525
1989-90	264,836	319.53	128.04	106.17	4,810	1,397
1990-91	263,638	386.62	124.96	106.14	5,022	580
1991-92	-	373.93	172.77	163.22	5,434	-

Note: 1 acre = 0.4047 hectare; 1 cusec (cfs) = 28.32 l/s.
Source: LRO Office, LCC East Circle, Faisalabad.

Table 11 Design Head Gauge vs Observed Head Gauge of Sample Channels in the LCC East Circle.

Distributary/ minor	Design head gauge (feet)	Average, observed head gauge, kharif 1992 (feet)							
		March	April	May	June	July	August	September	October
Lagar	1.89	1.45	1.58	1.66	1.65	1.63	1.50	1.41	1.62
Mananwala	5.20	4.34	5.01	5.07	5.08	5.14	5.10	4.81	4.68
Karkan	3.31	2.51	2.96	3.06	3.09	3.04	3.04	2.58	2.51
Yakkar	1.25	1.18	1.03	1.07	1.21	1.22	1.26	0.99	1.05
Bhun	1.10	1.01	1.08	1.14	1.31	0.94	1.04	1.07	1.08
Rajana	1.20	1.13	1.24	1.19	1.05	1.12	1.05	1.07	1.09

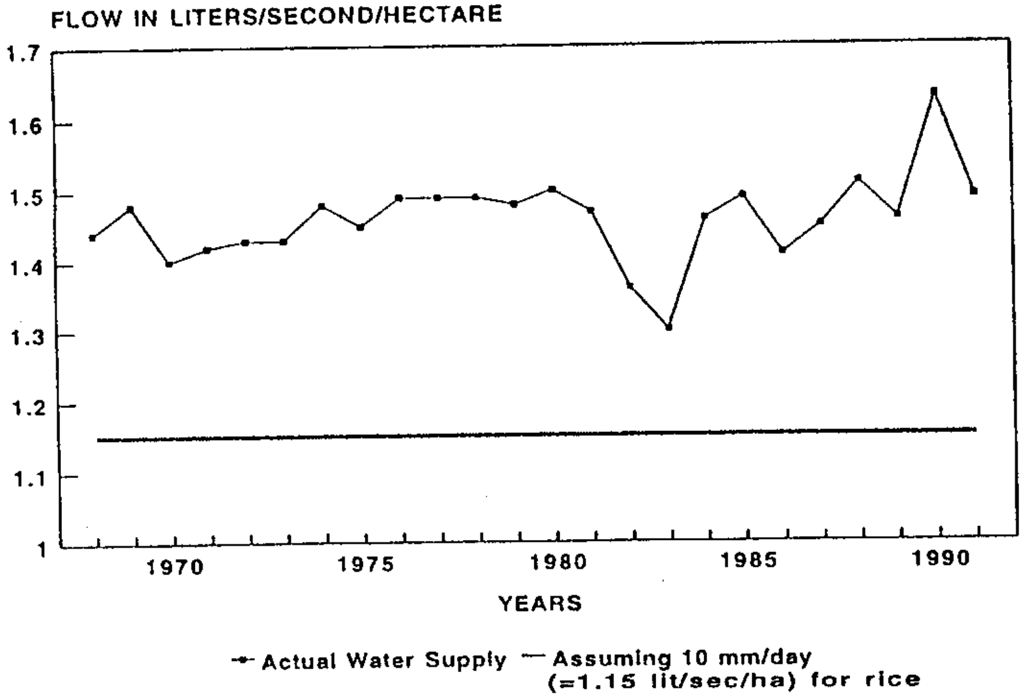


Figure 6 Canal Supply Allocated for Reclamation from 1968 to 1991 in Punjab.

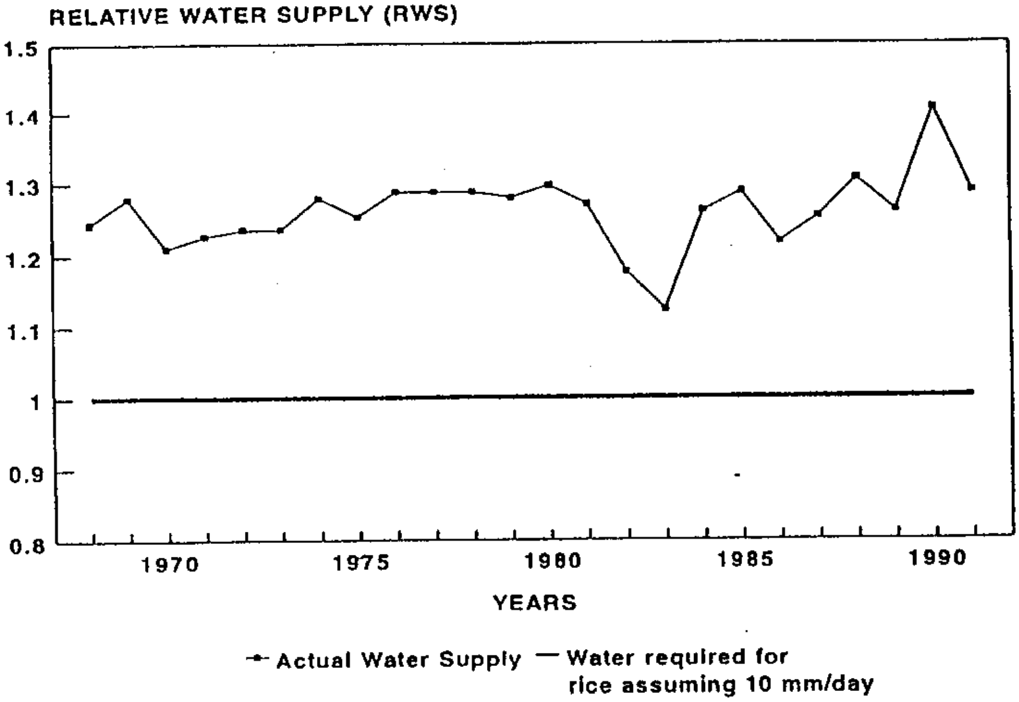


Figure 7 Irrigation Water for Reclamation in terms of Relative Water Supply (RWS) in Punjab (1968 to 1991).

reclamation shoots was sanctioned for the tail reaches of the distributaries where the incidence of salinity is usually the most.

To more effectively use the water potentially available for leaching requires a combination of a number of changes in current understanding, activities and procedures:

- The farmers must be educated about the needs and practices for maintenance of soil quality, with specific emphasis on leaching;
- The pattern, spatial and temporal, of surplus water must be determined;
- The formal and informal rules for regulating the operation of watercourses outlets, particularly at closure, must be evaluated and, if necessary, modified;
- The flexibility of within watercourse warabandi's must be enhanced in those areas subject to salinization;
- Effective water user organizations must be in place, to prevent abuse of flexible warabandi and to foster distributary level cooperation ahead of releases planned by the irrigation departments;
- Scientific soil testing methods should be introduced for the appraisal of soil salinity;
- The planning for the provision of reclamation shoots should include tail areas of canal commands; and
- Monitoring of the reclamation operations, both during and after their implementation, should be eprformed by the official agencies mandated for this purpose.

V. MANAGEMENT INTERVENTIONS: ISSUES AND OPTIONS

A. An Obsolete Reference

The present scope of policies for sustainable irrigated agriculture are linked to optimization of the water resource, i.e. productivity enhancements per unit of water (water duty, in official parlance). It is the scarcity of water that controls the decisions on land utilization and cropping practices. In the absence of an equitable distribution, howsoever the surplus of supplies in the system, the gains per unit of this resource diminish, thereby disturbing the entire gamut of linkage to productivity. From the management point of view, then, the contextual interventions required for the maintenance of equity across geographical scales requires a consensus amongst the managers. A rather common surface distribution system malaise in Pakistan is the absence of equity in the lower one-third reach of the channels. Its redressal in combination with a disaggregated understanding of within system canal performance should be the basis for system-level management interventions.

Punjab irrigation systems were designed to provide almost uniformity in equity: duties for all channels were essentially the same and, because the supplies were less than potential demand, the channels were expected to run at design discharges throughout the year. Almost doubling of the cropping intensities in many parts of the system has resulted in the distortion of the equity concept based on the design of the system, and resultant procedures for performance evaluation. For example, IIMI's sample research in parts of the LCC East (Rechna Doab) has shown stark variabilities in irrigation flows at the outlets during peak demand periods when considered in the context of applied *equity* set forth by the Irrigation Department (Table 12). It was estimated that in the investigated areas some 40% of the tail end areas do not receive any canal water at all, so that a gradual buildup of sodicity is inevitable. Surveys among farmers confirm this, as is apparent from the hardening of top soils, the decrease in the rate of infiltration and inadequate seed germination, all signs of the gradually worsening situation.

Utah State University studies refer to a possible alternative, the "*performance equity*" in which priority requirements are sought to be met based on a "performance equity value" which expresses how well an area is served from the beginning of an irrigation season upto a given stage in the season (Dr. Eisele, PhD thesis). This seems to be a more dynamic assessment, as its measure is described to be "a function of supply, demand and implicitly, the timing of supply", and contrasts with the traditional equity based evaluation, which is a static assessment against the design criteria. Such an approach is more likely to motivate managers and operators, as it takes into consideration the variables that are mostly under their control.

The gap between original design criteria and present levels of system performance may be only partly caused by management deficiencies, whereas partly, it may be due to the "unmanageability" of all, or some, of the original criteria within the present policy environment. Attempts at refining the data base on physical aspects is likely to be less productive as some conclusions on the degree of inequity and variability have already been reached, and appear to be sufficiently convincing, as demonstrated by IIMI research in the LCC system and elsewhere. An undue emphasis on performance ratings in the absence of mechanisms to translate irrigation and agriculture data into management information would be institutionally irrelevant and technically infeasible (Bandaragoda, personal communications, 1996).

Moreover, in practical terms, system objectives are also related to other important variables, such as the environment, technology, human skills and awareness, and availability of resources. When considerable time has elapsed since the design of the systems, the effect of these variables warrants a review of objectives. Thus, attempts at matching existing

Table 12. Variation in Outlet Discharge During Peak Demand Period in the Lower Chenab Canal (East) Circle, Rechna Doab, Punjab, Pakistan.

Distributary/Watercourse*	CCA (ha)	Design Discharge (lps)	Water Allowance (l/hr/ha)	Percentage of Design Discharge					
				May	June	July	August	September	October
UPPER GUGERA COMMAND									
Mananwala 24873-R	171	24.4	8.53	135	141	157	195	212	176
Mananwala 43506-R	225	29.7	7.94	88	89	77	92	92	91
Mananwala 71683-R	289	38.2	7.94	113	113	99	116	116	116
Mananwala 87670-R	240	47.9	11.96	185	189	176	207	214	212
Mananwala 121735-R	255	33.7	7.94	129	128	0	133	129	129
Mananwala 141542-R	514	68.0	7.94	38	24	0	25	0	0
Karkan 10435-R	158	31.4	11.94	103	107	87	101	122	107
Karkan 54892-R	231	46.2	11.96	78	82	0	96	98	102
LOWER GUGERA COMMAND									
Pir Mehal 70076-R	187	37.1	11.87	72	69	79	68	60	67
Pir Mehal 89250-L	174	46.2	15.87	58	56	64	52	45	48
Pir Mehal 133970-L	223	44.2	11.88	83	85	93	84	82	84
Junejwala 6619-R	118	31.1	15.86	100	114	99	103	119	109
Junejwala 27290-R	141	31.1	13.30	145	151	134	169	165	173
Junejwala 41234-L	159	31.7	11.93	86	94	68	96	93	90

* IIMI Sample Outlets of the LCC East Circle

Table 13. Descriptive Profile of Irrigation Related Parameters in the Canal Administrative Divisions of the LCC System, Rechna Doab, Punjab, Pakistan.

LCC East Circle	CCA (ha)	Outlets	Discharge (Cumecs)	Length (km)
Upper Gugera	230630	1127	37.4	651.81
Lower Gugera	206412	1039	46.13	593.16
Burala	185391	960	51.61	546.68
Total	622433	3126	135.14	1791.65
LCC West Circle				
Hafizabad	138547	766	28.26	385.27
Faisalabad	129393	870	27.34	405.96
Jhang	224619	1074	58.87	702
Total	492559	2683	114.47	1493.23

management activities with design criteria are only of academic interest. In such situations, the focus of irrigation management research should be towards comprehensive "system renewal" whereby emphasis is placed on resource mobilization rather than impact assessments based on original system objectives. For example, it is frustrating for the manager to face numerous evaluations which simply ignore the budgetary constraints that restrict his flexibility to perform. Inadequate or pre-determined fixed allocations are likely to impinge negatively on system management.

B. System Management Reforms

Future research in Pakistan at the sector level could include issues such as decentralization of state control, intra- and inter-provincial competition for water-related investment strategies, and the systematic conversion from a supply to a demand driven system. Organizational changes may also be necessary; for example, questioning the sense to have an irrigation circle, drainage circle, and a SCARP circle in an already inflexible administrative setup. This multi-jurisdictional reporting complicates the task of systematic and integrated monitoring of the environmental and agricultural conditions, thereby leaving little scope for the translation of irrigation and related agricultural policies into remedial actions at the field operations level.

In the context of decentralization of state control, as cited above, the key areas requiring systematic scrutiny are (Merrey, 1979):

- The imbalance focused on technical issues at the expense of local organizational issues;
- The inappropriate interventions at local levels through proliferation of agencies and concentrations of control at high levels of the state;
- Inability to respond to local problems until they reach crisis proportions;
- Vulnerability of the larger system to unmanageable crises;
- Transition from system-serving institutions to self-serving institutions;
- The level of conversion and extent from a supply driven system to a demand driven system; and
- Responsiveness of the physical system to local demands and autonomy in management.

The addressals above are a direct consequence of the continued policy of hyperintegration of institutional and process control as functionally bequethed to the administrative units in

Pakistan by the colonial vestige. The resultant pathological tendencies to be meddlesome in lower order affairs have been the principal constraints to social organization on the one hand and redirection of O&M expenditures towards achieving reliable and equitable flow distribution on the other.

PART B

VI. INVENTORY OF THE RESOURCE BASE

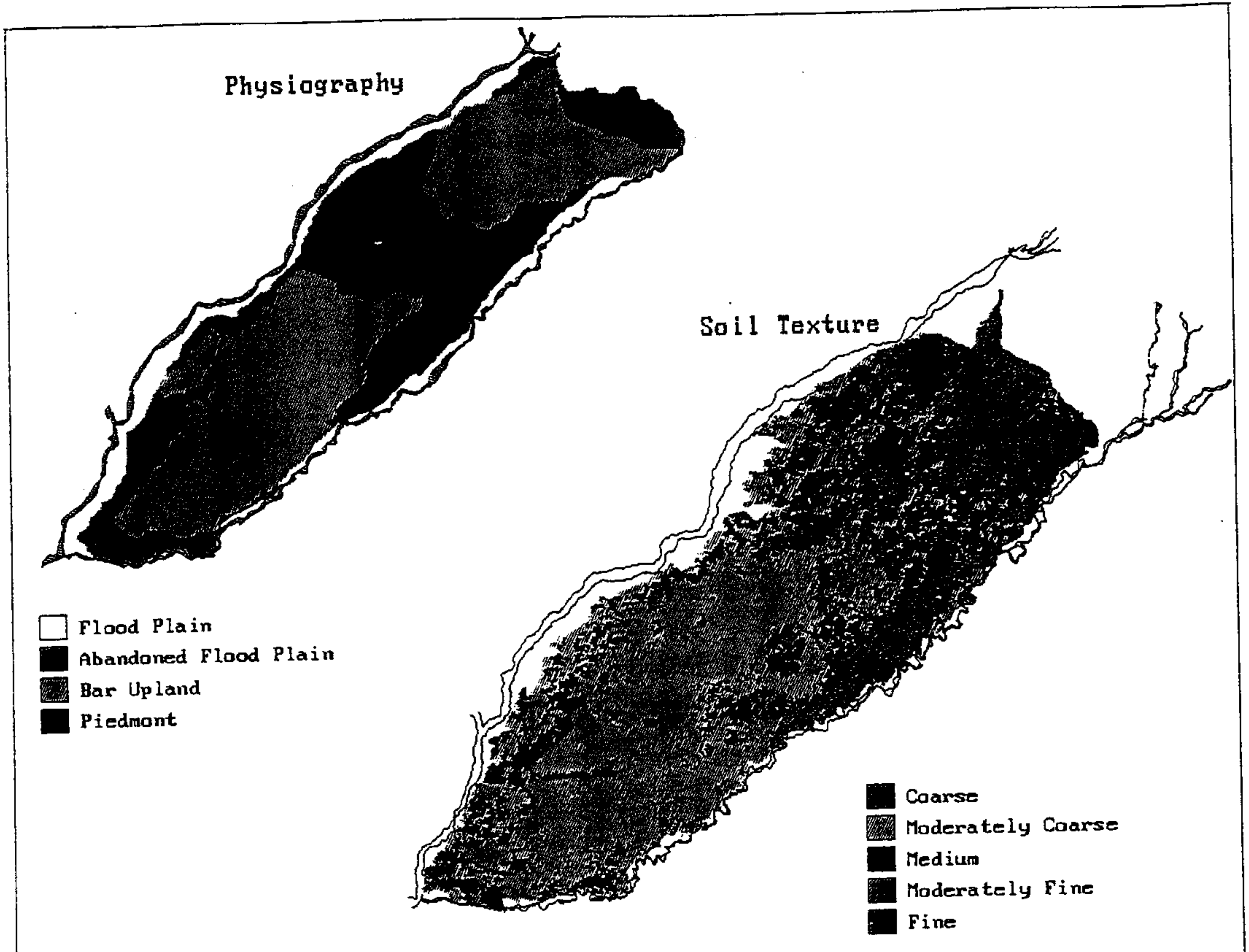
A. Physiography and Soils

Rechna Doab, as part of the alluvium filled Indo-Gangetic plain, comprises 2.975 Mha of gross area that trends southwesterly to a topographic relief difference of 113 m (Figure 1). The average slope of 0.37 m/km across the 390 km length of the doab decreases by about 25% in the lower reaches. In continuation of the definition of the physiography of the doab, the SSoP has identified 4 distinct landforms on the basis of degree of soil development, surface configuration, and relative elevations (Figure 8(a)). Bar uplands are the oldest land form and comprise the flat-topped river terrace locally known as the Sandal Bar. The soil material for the Bar Uplands is predominantly medium textured with weak structure in the subsoil; moderately coarse materials are probably parts of old levee deposits. Within the channel-levee remnants, there are numerous patches of saline-alkali soils with dense subsoil structure, low porosity and a strong kankar (nodule) zone at a depth of 1 m. The silt loam texture may be partly covered by sandy deposits.

Abandoned flood plains comprise the early Holocene deposits of the rivers and occur in the Chenab Plain to the north and the Kamalia Plain to the south. The soils in the Kamalia Plain are mostly silt loams with weak subsoil structure and no kankar zone. The Chenab Plain has deeply developed loams and silt loams with sandy composition in the undulating parts (suitable for dry-farming). The surface is generally level and lies above the present flood levels. The young and active flood plains stretch in a narrow belt along the rivers and comprise stratified silt loams to very fine sandy loams to a depth of 1 m that is underlain by sand.

Overlying the Precambrian metamorphic or igneous rocks in the basement, the unconsolidated alluvial deposits are of Pleistocene to recent age deposited through the continuing meandering flows of the river systems that developed since ancient times. The sediments in the upper part of the doab consist of medium to fine sand, silt, and clay. Gravel and coarse sand are uncommon. The origin of clays could not be identified specifically, but these are presumed to be the repeatedly reworked loess deposits of the hills at the north and northwest. Though the alluvium complex is of heterogeneous nature (thickness unknown), yet it forms a fairly transmissive unified aquifer. In some areas, the soils are fairly homogeneous containing high percentages of silt and fine to very fine sand; clay contents are higher only in depressional areas.

The earliest soil survey was, however, done by the WASID during the early sixties involving profile sampling to a depth of 180 cms. A minimum of four bore holes per square mile, in addition to shallow confirmatory bores, were augured for delineating soil boundaries. For



Source: WAPDA, 1978

Figure 8 Physiography and Soil Series Maps of Rechna Doab, Punjab, Pakistan.

the 15-180 cms of strata, the soils were classified into 5 series based on both vertical and horizontal textural variations. The series names are explained as follows:

Jhang Coarse (sand and loamy sand)

These soils are very permeable, usually slightly calcareous, and seldom have a zone of lime accumulation. Owing to their coarseness, these soils are unlikely to build up higher levels of salinity or fertility.

Farida Moderately Coarse (sandy loam and fine sandy loam)

These are the most extensive soils in the Rechna Doab. Derived from older alluvial deposits, they are generally found on smooth, nearly level topography. the surface is mildly calcareous, whereas the subsoils are moderately to highly calcareous. With a wide range of adaptation, the fertility levels and organic matter can be readily built up.

Buchiana Medium (Loam, silt loam, and silt)

These soils also have been derived primarily from the older sediments. Being moderately permeable, they have good to high water holding capacities that make them the most favorable soils for farmming. Kankar zones are frequent in the upper substratum, particularly in areas where the watertable has fluctuated within the soil crust.

Chuharkana Moderately fine (silty clay loam, sandy clay loam, clay loam)

Occuring across depressional or semi-depressional areas, these soils have a compact substrata that supports a rather narrow range of crop adaptation. Because of limited drainability, the salinity hazard for these soils is much more pronounced, especially when accompanied by high watertables.

Nokhar Fine (sandy clay, silty clay, and clay)

The substrata of these soils is commonly of moderately fine texture. The internal drainage is highly restricted and surface drainage features are unfavorable. Extent-wise, they are only a small fraction of the Rechna Doab.

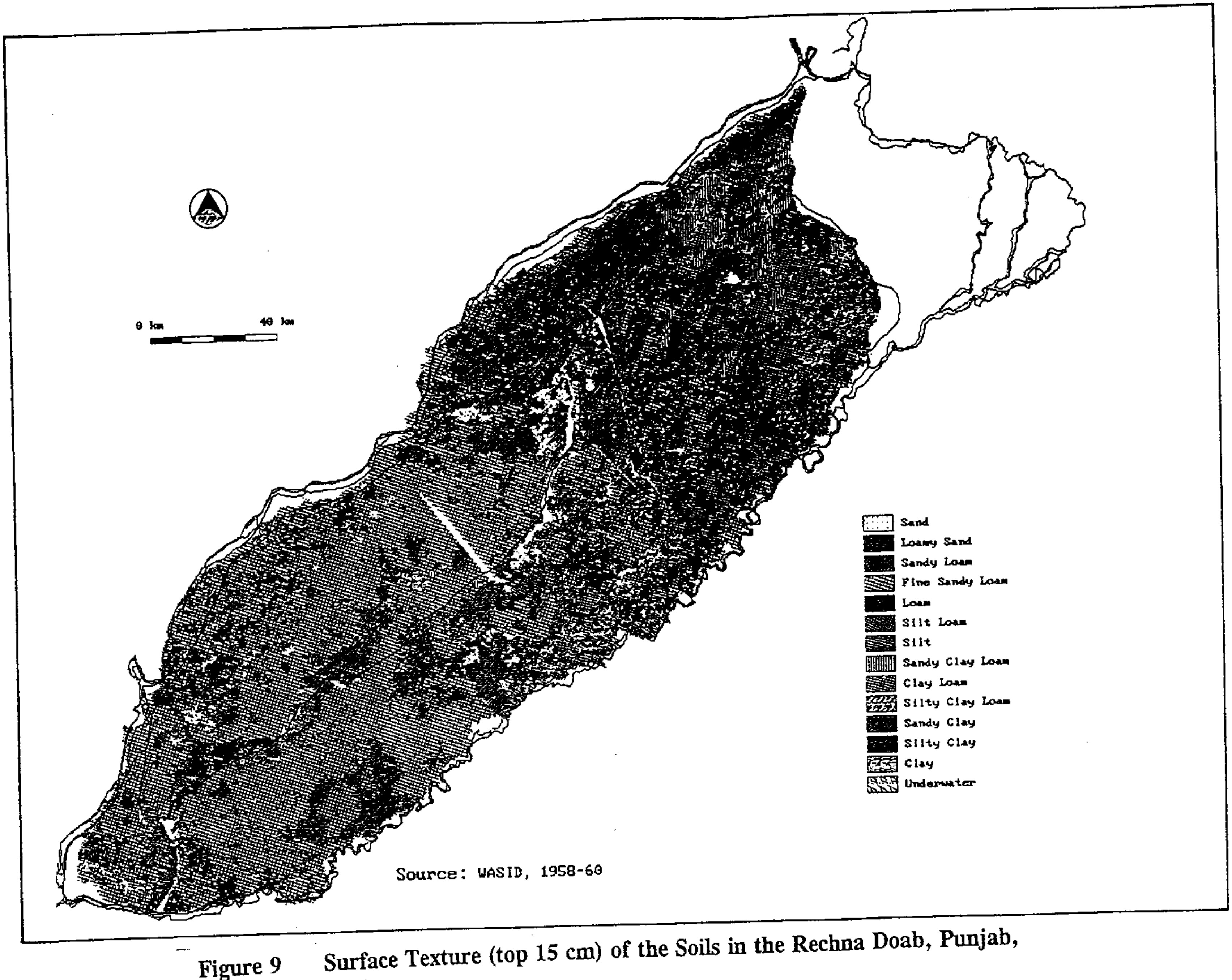
Figure 8(b) shows the spatial distribution of the soil series described above. Areas in Upper Rechna are primarily moderately fine that transition to predominantly medium textures across the mass of the abandoned flood plain of the Chenab further south. The area below the Q- B Link land is a continuous extension of the Farida series with coarser fractions of Jhang also involved between Lower Gugera and Burala branches of the irrigation system to the east and closer to Jhang in the west. Moderately fine patches reappear in the extreme south, but are limited to the command of the Koranga feeder from across Sidhnai.

For the initial 15 cms of the soil strata representing the top root zone, the results of WASID's investigations are mapped in Figure 9 with canal command differentiation. These surface soils show much more heterogeneity as compared to the series mentioned above. Since all the five soil series described above also have phases, attempts at cross correlation with the surface texture are unlikely to achieve satisfactory congruence. For example, while the pattern of sandy loam and fine sandy loams in the upper crust is significant in association to the extents of the moderately coarse Farida soils across the lower two-third of the doab, loam and the fine sandy loam crust in the upper one-third are anamolous for the predominantly clayey stratums beneath.

The 1965-68 survey by the Soil Survey of Pakistan (SSoP), based on the interpretation of the aerial photography available for the area, has classified the soils on the basis of genetic characteristics at a reconnaissance level. More emphasis has been laid on factors like porosity, structure, consistency, and drainage. The distribution of these soils across the Rechna Doab in terms of associations and their constituting series has been given in Figure 10 under respective landforms that are derived from the parental grouping appearing in Figure 8(a) above. In lieu of the tremendous diversity of these classifications at the doab scale, a discussion on the individual merits of these compositions is not deemed fit for this introductory note. A rather detailed description of the soil associations within Rechna Doab appears in Vol. VII of this report.

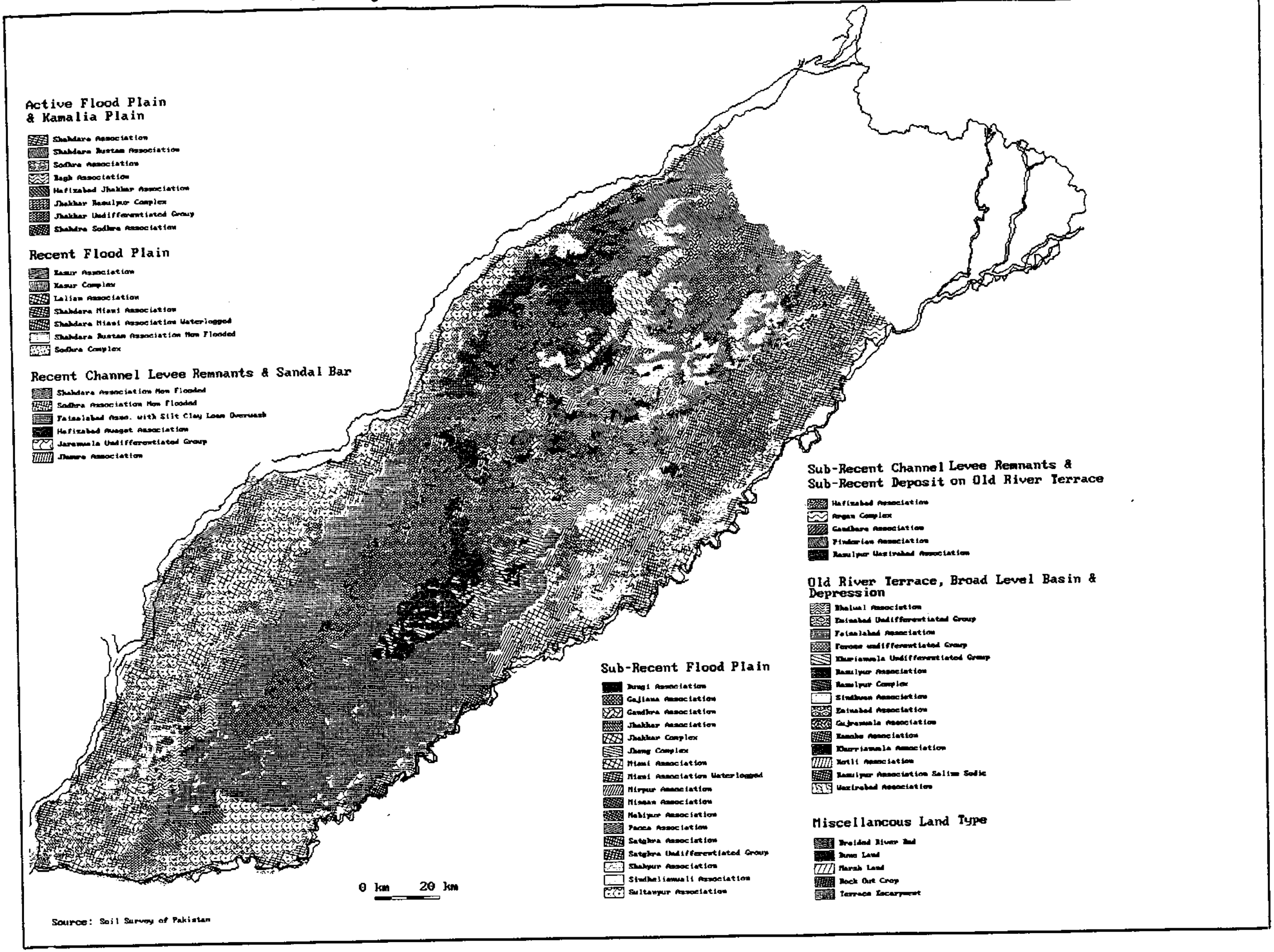
On the basis of *analytical* data, the soils have been divided into two broad groups normal soils and saline-sodic soils. The normal soils are non-saline and non-sodic, relatively porous and well structured with lime accumulation generally below 120 cm depth. The saline-sodic soils are divided into two categories; namely dense saline-sodic and porous saline sodic (Figure 11). The dense saline-sodic soils with a 60-130 cm thick B horizon are non-calcareous to strongly calcareous. The hydraulic conductivity of these soils is very slow, having median values of 0.18 cm/day for silty clay loam and 0.3 cm/day for silt loam. In comparison, for non-saline and non-sodic soils of sandy clay to sandy clay loam texture, the normal hydraulic conductivity ranges between 11-14.5 cm/day. The porous saline-sodic soils are moderately calcareous and comprise silty clay, silty clay loam, silt loam and loam.

Within the Rehna Doab, the distribution of porous soils is within four distinct clusterings: along the borders of the active flood plain below Khanki headworks; the head reaches of the Jhang, Rakh and Gugera branches; the tail portions of the Jhang branch and head reach of the Haveli; and the very tail portions of the Lower Gugera network. This distribution broadly overlaps the medium soils identified earlier by WAPDA in their soil series classification. For the dense subsoils, the aggregate groupings occur most extensively in the commands of the UCC parallel to the Ravi River and the head reach of the LCC system. Much smaller but wider scattering of these soils occurs within the entire Upper Gugera Branch canal command area. The tail command of Lower Gugera and the areas



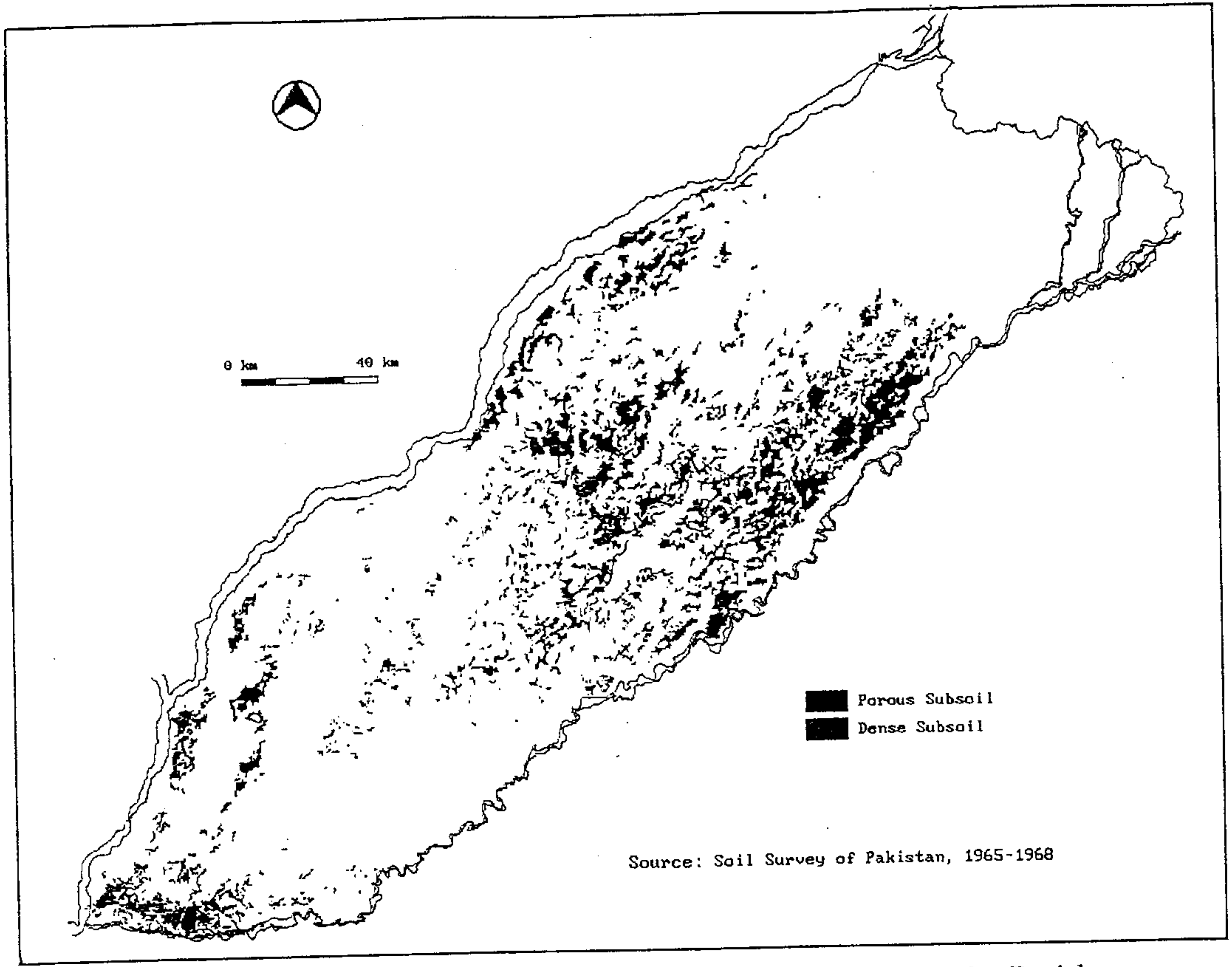
Source: WASID, 1958-60

Figure 9 Surface Texture (top 15 cm) of the Soils in the Rechna Doab, Punjab, Pakistan.



Source: Soil Survey of Pakistan

Figure 10 Reconnaissance Level Soil Association Classifications for the Rechna Doab, Punjab, Pakistan.



Source: Soil Survey of Pakistan, 1965-1968

Figure 11 Distribution of Saline Sodic Soils within Rechna Doab, Punjab, Pakistan.

commanded by the Koranga Feeder canal represent a combination of both porous and dense saline sodic soils that have an almost unbroken expanse from near the outfall of the T-S Link to the confluence of the Chenab and Ravi rivers. It is here, and in the commands of the UCC that WAPDA's moderately fine soil series differentiation coincides well with the mapping of the dense saline sodic soils by SSoP.

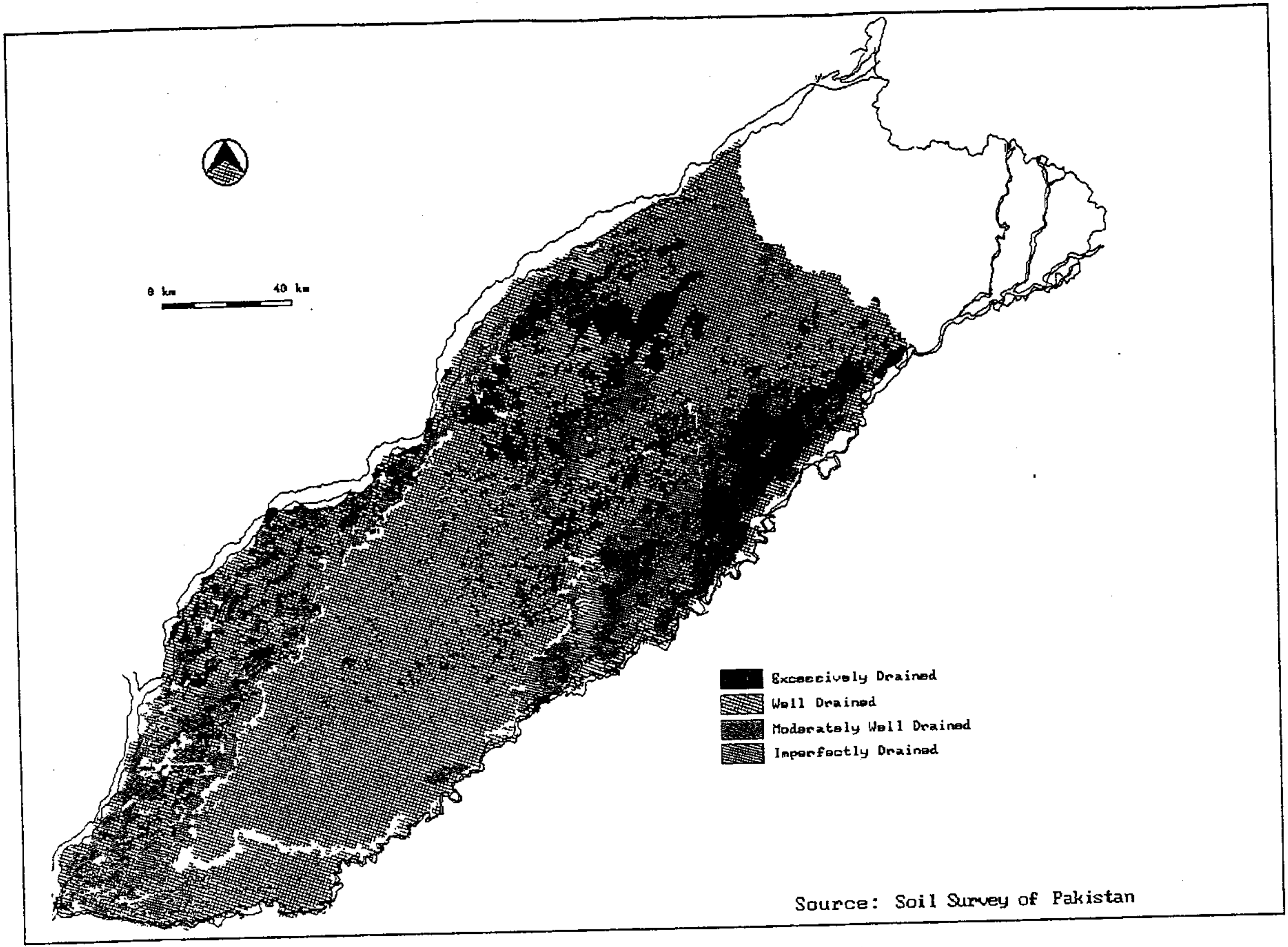
Soil Survey's drainage classification relies on a combination of textural and relief information derived from the associations and series identified earlier in Figure 10. The drainage has been broadly categorized as excessively drained, well drained, moderately well drained, and imperfectly drained soils. The distribution of these drainage categories within the Rechna Doab is provided under Figure 12.

The excessively drained soils are sand to loamy sand fractions occupying higher channel deposits or as dunelands. These soils are limited mostly to the commands of the distributary offtakes from the LCC Main Canal; the occurrence is most extensive near Hafizabad and the tail commands of the UCC's Nokhar Branch Canal. Strip continuations of these soils also occur along the middle to tail reach of the Jhang Branch Canal. The well drained soils are a mix of homogenized and well structured loams, silt loams and silty clay loams situated on level to gently sloping terrain. Spatially, they are most dominant across the central longitudinal axis of the doab. Their continuation is interrupted to the east by the moderately well drained categorizations in the Mangtanwala and Muridke units of SCARP-IV (eastern UCC command). Elsewhere, they form a mixed culture along the Chenab southwards of the Qadirabad Barrage that extends to the commands of the Haveli canal and the Koranga Feeder Canal near the interfluvial confluence.

For the increasingly clayey constituents occurring in the channel infills and level to concave basins, the SSoP provides a moderately well drained classification for the soil composition. Besides the occurrence in the abandoned flood plain of the Ravi River (SCARP-IV units) above, they are distributed parallel to the active flood plain of the Chenab River northwards of Jhang, and also within the flood plain below Trimmu Barrage. Finally, it is when the drainage becomes restricted, due to swelling clays in distinct depressions typically collecting the runoff, that the soils are regarded to have imperfect drainage. Their presence is sparse in the tail reaches of the Jhang and Lower Gugera Branch Canal networks and somewhat mixed with the moderately well drained conditions in the eastern UCC command.

B. Groundwater Reservoir

The alluvial material in the Rechna Doab forms part of the extensive heterogeneous and anisotropic unconfined groundwater reservoir underlying the Indus Plain and is more than 300 meters thick. In the upper reaches of the doab, the alluvial plain overlaps an older rock formation. The upper 200 meters, as described by Greenman et. al. (1967), is composed of a thick sequence of alluvial sand, silt, and clay that has been laid down since late Tertiary time by the Indus River and its tributaries. Recurrent floods and frequent changes in the



Source: Soil Survey of Pakistan

Figure 12 Soil Drainability, Rechna Doab, Punjab, Pakistan.

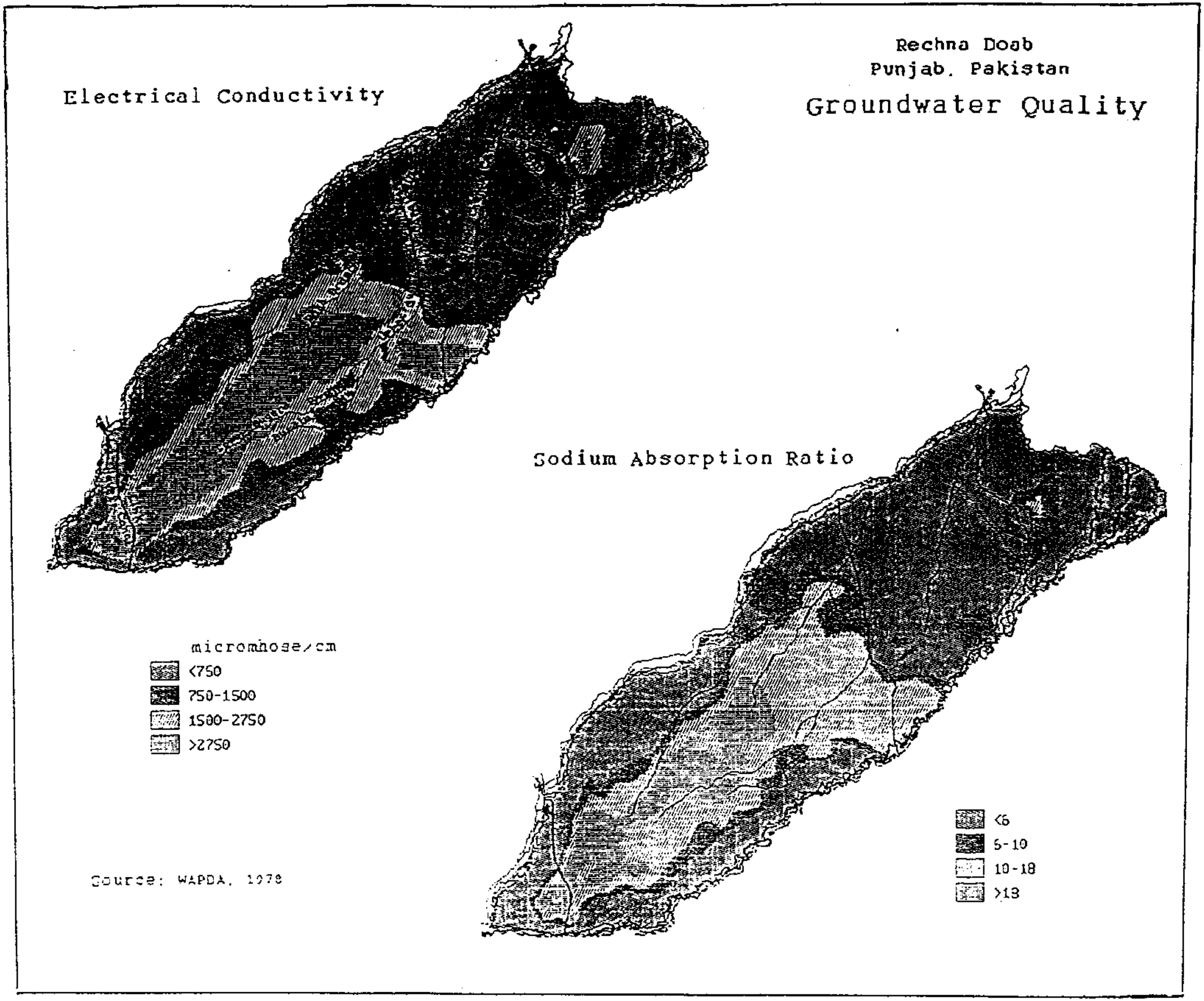
rate of flow caused the streams to meander back and forth across the land surface in a braided pattern of irregularly shifting channels.

The underlying deposits have little vertical or horizontal continuity. The bulk of the alluvium is composed of silt and fine sand, or mixtures thereof, with an absence of thick layers of pure clay. The material is highly porous and is capable of storing and transmittig water readily, the horizontal permeability being greater than the vertical (Bennett et. al., 1967). In the upper reaches of the doab, the alluvial complex consists principally of fine to medium sand, silt and clay. The porosity of the water bearing material ranges from 35 to 45 percent with an average specific yield of about 14%. The uniformity coefficient, defined as the ratio of 40% particle size to 90% size retained, ranges between 2.5-5.

Topographically, the interfluvial region of the Rechna Doab is flat with little natural drainage. It is underlain by a deep, unconfined , high yielding aquifer that is relatively homogeneous and highly anisotropic. Bennett, et. al. (1967) provide a detailed hydrologic description of the aquifer. They give the mean values of the hydraulic conductivities as 0.0012 and 0.000015 m/s in the horizontal and verttical directions, respectively. The much lower vertical permeability is due to the presence of clay layers in an otherwise fairly coarse sandy aquifer. The specific yields with the watertable in the sand layer and the clay layer are, respectively, 0.15 and 0.06. It is desirable, therefore, to install tubewells so that the screen length will not fall within the thick clay layers.

Despite the anisotropic nature of the alluvium that prevents regional movement of water across different depths of the aquifer, tubewells can be operated anywhere with specific drawdowns averaging 4.6 cm/lps. This variation in lithology imparts a wide range of hydraulic properties and different chemical characteristics to groundwater and, consequently, the wells screened opposite the most permeable sand lenses may pump water of different chemical quality from different horizons. The groundwater discharge from each well is a mixture from the several water-bearing zones and represents the average water quality that has been imposed by local geological conditions, the rate of pumping and the hydraulic characteristics. The sampling from wells distributed areally over the aquifer do not necessarily indicate the upper or lower limits of TDS concentration, but in general, show the distribution pattern of the water quality in the upper few hundred meters of the groundwater reservoir affected by pumping. Based on the sampling conducted to date by WAPDA, the differences in groundwater quality across the doab in terms of the total salt concentration (measured as electrical conductivity) and the proportion of sodium in solution (SAR) is shown in Figure 13.

The areal and vertical distribution of fresh and saline groundwater in the Rechna Doab principally is the result of circulation in the reservoir. Flow of groundwater from areas of recharge to areas of discharge is 3-dimensional along curvilinear flow paths controlled by vertical differences in hydraulic head. The dissolution of the chemical constituents is in part dependent on the composition of the material through which it moves, the residence time that the water is in the aquifer, the length of the flow path, water temperature, the chemical



Source: WAPDA, 1978

Figure 13 Electrical Conductivity and Sodium Adsorption Ratio (SAR) of the Groundwater in the Rechna Doab, Punjab, Pakistan.

composition of the recharge, besides base exchange and adsorption of dissolved ions amongst themselves. Studies by Swarzenski (1968) pointed out that the boundaries between saline and fresh water are not sharp; rather, mineralization gradually increases with depth and distance from sources of recharge. Neither the fresh nor saline groundwater can be defined as separate and distinct bodies in terms of stratigraphic position.

Recharge from canal seepage and infiltration of irrigation water has superficially modified the vertical and areal distribution of fresh and saline groundwater bodies that existed in the pre-irrigation period. Canal seepage locally diluted brackish groundwater and increased circulation creating lenses underneath, however, the impact of this change is not uniform along the canals due to stratifications and anisotropic conditions.

Other modification in the distribution patterns of saline and fresh water are due to the disproportionately large evaporation losses brought about by irrigation practices and waterlogging problems. In areas where the watertable has risen to or near the land surface, evaporation has increased mineralization of the groundwater at shallow depths, whereby it is not uncommon to find water of relatively poor quality overlying water of better quality.

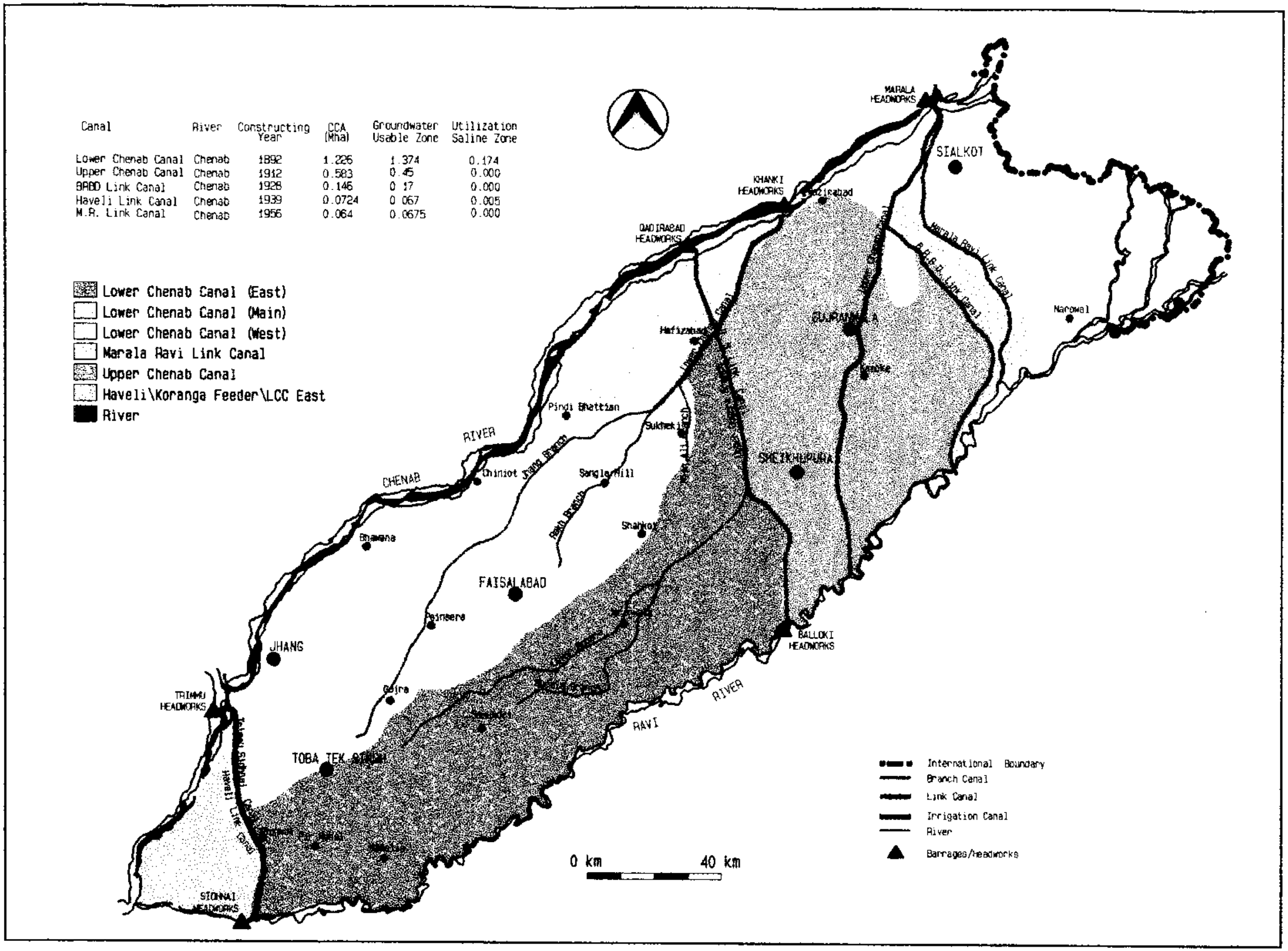
Flow net changes due to increased pumpage has locally induced inflow of brackish water toward pumping centers. The increased circulation, particularly in the vicinity of canals, has gradually decreased the mineralization of the groundwater that resulted in a more homogeneous composition. While hydrologic equillibrium gets reestablished, it is less likely to happen for the chemical equillibrium.

VII. DEVELOPMENT OF IRRIGATION INFRASTRUCTURE

Much of the present day irrigation in the Rechna Doab is commanded by two major canals; Upper Chenab Canal (UCC) covers the bulk of the upper one-third of the system, whereas Lower Chenab Canal (LCC) has extensions even beyond the parallel run of the Haveli and TS Link canals in the south (Figure 14). The planning for both or these canals was initiated jointly in 1887; however, the construction of LCC was started in 1889 and completed by 1892, ahead of the same for the UCC in 1915. Along with the other canal systems in the doab, a total of 2.39 Mha of land is under perennial and non-perennial irrigation. Non-perennial irrigation is restricted to Upper Rechna in the commands of the Upper Chenab and Marala Ravi Link canals.

A. Upper Chenab Canal

The Upper Chenab Canal was part of the Triple Canal Project (including Upper Jhelum and Lower Bari Doab canals) completed in 1915 which, in addition to main irrigation uses within



Canal	River	Constructing Year	CCA (Mha)	Groundwater Usable Zone	Utilization Saline Zone
Lower Chenab Canal	Chenab	1892	1.226	1.374	0.174
Upper Chenab Canal	Chenab	1912	0.583	0.45	0.000
BRBD Link Canal	Chenab	1928	0.146	0.17	0.000
Haveli Link Canal	Chenab	1939	0.0724	0.067	0.005
M.R. Link Canal	Chenab	1956	0.064	0.0675	0.000

- ▩ Lower Chenab Canal (East)
- ☐ Lower Chenab Canal (Main)
- ☐ Lower Chenab Canal (West)
- ☐ Marala Ravi Link Canal
- ▨ Upper Chenab Canal
- ☐ Haveli\Koranga Feeder\LCC East
- ■ River

Figure 14 Canal Command Map of the Rechna Doab, Punjab, Pakistan the system, also feeds the Lower Bari Doab Canal through the BRBD Link Canal. It serves a total CCA of 0.59 Mha of which 0.34 Mha are in the Upper Rechna (the canal extends to areas further south to the east central portions of the doab). The designed capacity discharge for the UCC at the head is 467 cumecs of which 151 cumecs are for diversions within the doab during Kharif and 52 cumecs during Rabi. Of this allocation, 82 and 32 cumecs, respectively, are consumed within the Upper Rechna during Kharif and Rabi. The supply factor for the system (actual diversion/authorised full supply) is 0.76 for Rabi and 0.91 for Kharif.

The UCC trifurcates in the Upper Rechna near Daska resulting in Nokhar Branch Canal, BRBD Link Canal, and Main Line Lower Canal. Nokhar Branch Canal is non-perennial with an authorised full supply (AFS) of 20 cumecs; BRBD contributes 17 cumecs out of 146 cumecs as non-perennial supply; and the Main Line Lower Canal supplies 45 cumecs in the Kharif and 32 during Rabi. The MR Link Canal, as a carrier for the Central Bari Doab and Dipalpur canals, contributes 27 cumecs of non-perennial supply to areas in Upper Rechna; the LCC contributes 22 cumecs through four non-perennial distributaries to a gross commanded area of 58,264 ha.

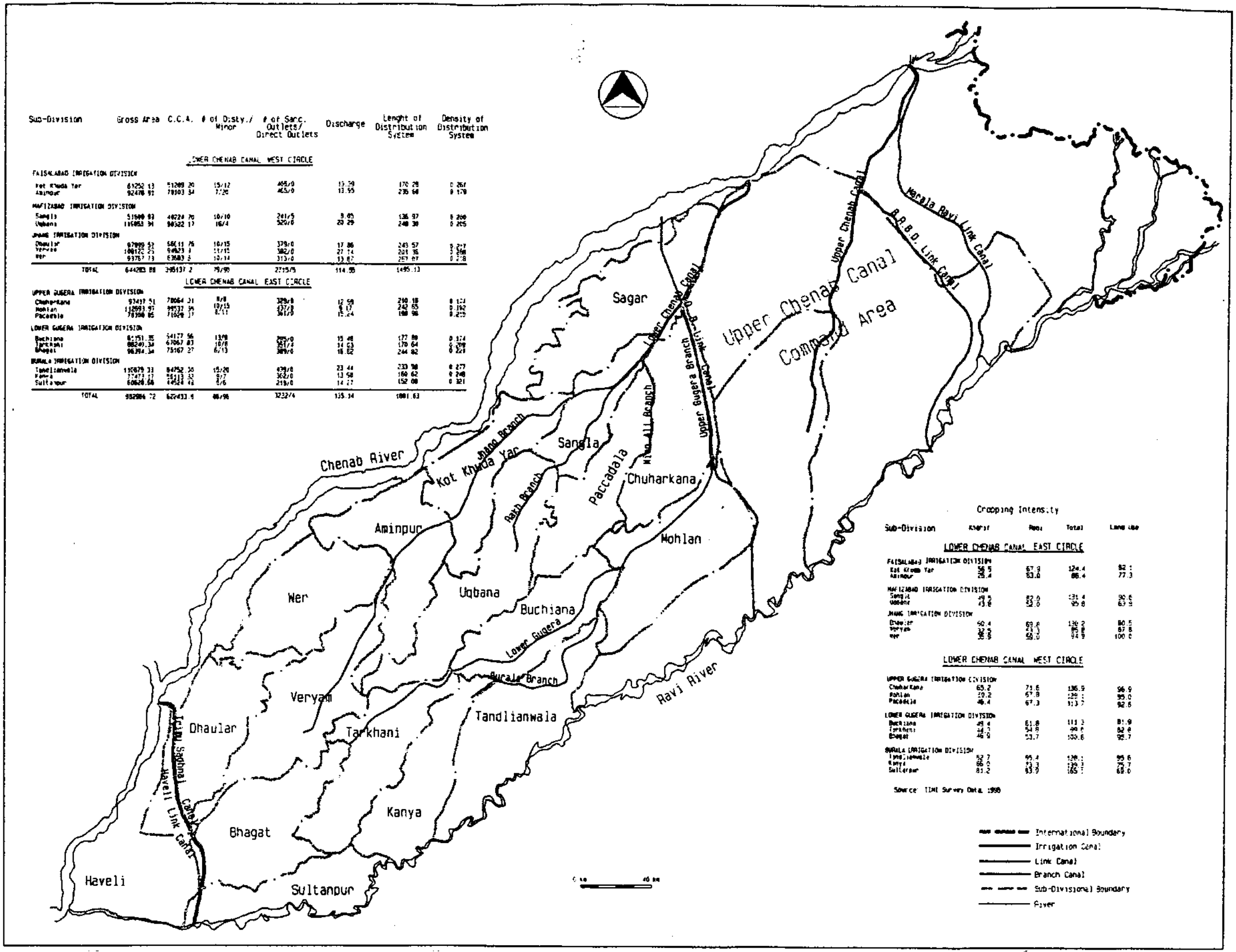
B. Lower Chenab Canal

The LCC by comparison is more than double the size of UCC and, other than the non-perennial supplies to the Upper Rechna (distributary offtakes from the Main line downstream of Khanki Headworks), is completely perennial. The major statistics of the system appear under Figure 14. Because of its huge size (CCA 1.226 m hac.) the system has been bifurcated into eastern and western halves or canal circles, the former comprising the commands of the Upper & Lower Gugera and Burala branches, whereas the latter includes Rakh and Jhang branches.

Administratively, below the canal circles, the LCC is divided into Divisions and Subdivisions, each consisting of its own set of channels and sanctioned outlets (Figure 15). Across the subdivisinal divides, the CCA's vary from 50,000-120,000 ha with Rabi cropping intensities being invariably higher than Kharif. Normally, upto three subdivisions combine to make an irrigation division, which is the largest aggregation under a canal circle. A comparison amongst the six irrigation divisions within the LCC indicates Jhang, under LCC West Circle, to be the largest in terms of CCA, sanctioned outlets, discharge, and the total length of the distribution system at the secondary level (see Table 13, page 34). However, it is the LCC East that has the higher values of statistics for comparisons at the Circle level.

C. Flow Variations

Variations in canal allocations specific to the LCC system are explained in Figure 16. For the pre-Water Apportionment Accord water year period, the flows in the Jhang Branch



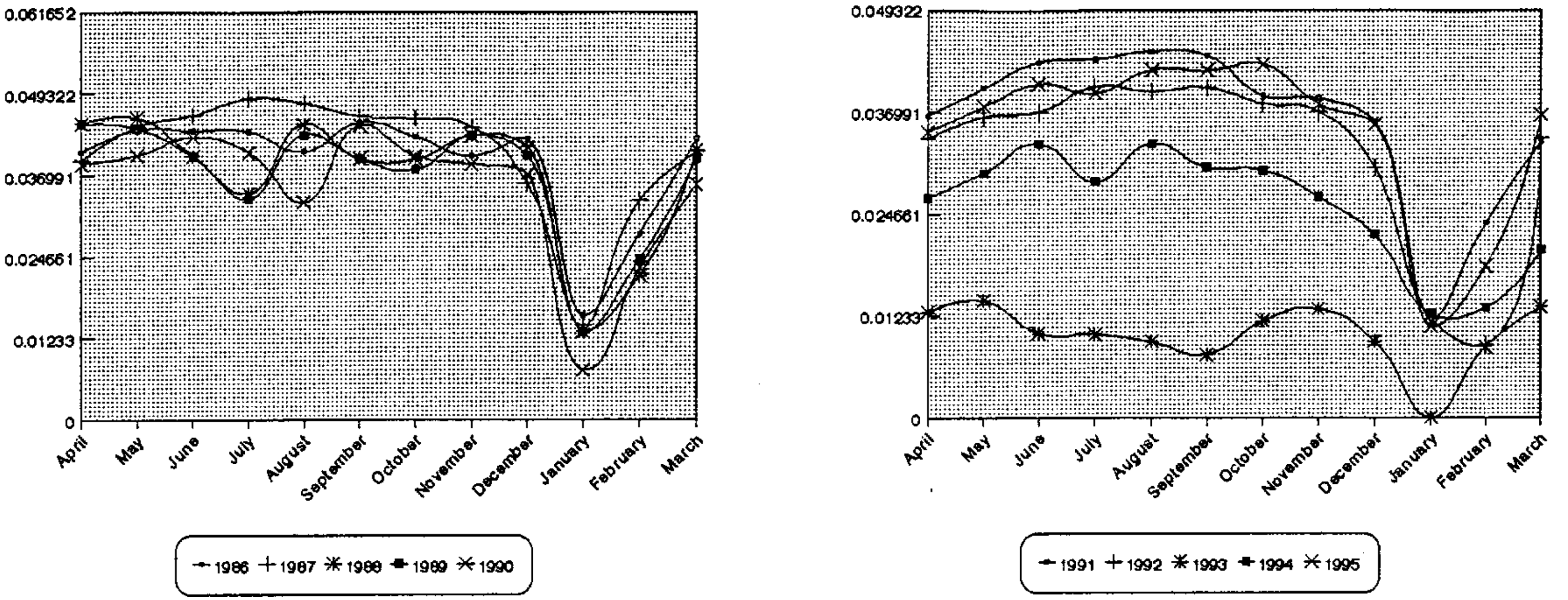
Sub-Division	Gross Area	C.C.A.	# of Disty./ Minor	# of Sanc. Outlets/ Direct Outlets	Discharge	Lenght of Distribution System	Density of Distribution System
LOWER CHENAB CANAL WEST CIRCLE							
FAISALABAD IRRIGATION DIVISION							
Kot Khuda Yar	61252.13	51209.20	15/12	405/0	13.39	170.29	0.267
Aminpur	92478.92	78103.34	7/20	465/0	13.55	235.64	0.179
HAFIZABAD IRRIGATION DIVISION							
Sangla	51600.93	40224.70	10/10	241/5	9.05	136.97	0.200
Uqbana	115053.94	98522.17	16/4	520/0	20.29	240.30	0.205
JHANG IRRIGATION DIVISION							
Dhaular	97899.52	56011.76	10/15	379/0	17.86	243.57	0.247
Veryam	100122.25	94823.3	11/15	382/0	27.14	201.35	0.268
Wer	93767.73	63603.3	10/14	313/0	13.87	257.87	0.278
TOTAL	644283.88	395137.2	79/90	2715/5	114.55	1495.13	
LOWER CHENAB CANAL EAST CIRCLE							
UPPER GUGERA IRRIGATION DIVISION							
Chuharkana	97437.51	78064.31	8/8	329/0	12.59	290.18	0.134
Mohlan	112093.97	99537.59	10/15	437/0	9.17	242.65	0.192
Paccadala	78300.05	71029.17	8/11	361/0	15.24	198.98	0.215
LOWER GUGERA IRRIGATION DIVISION							
Buchiana	61351.35	54177.56	13/8	285/0	15.48	177.80	0.174
Tarkhani	88240.34	67067.83	10/8	351/4	14.63	170.64	0.209
Bhagat	96394.34	75167.27	6/13	309/0	16.82	244.82	0.221
BURALA IRRIGATION DIVISION							
Tandlianwala	110879.33	84752.30	15/20	439/0	23.44	233.90	0.277
Kanya	77473.17	56113.32	9/7	362/0	13.58	160.62	0.240
Sultanpur	60620.60	44524.41	5/6	219/0	14.27	152.00	0.321
TOTAL	982906.72	622433.4	86/96	3232/4	135.34	1881.63	

Cropping Intensity

Sub-Division	Kharif	Rabi	Total	Land Use
LOWER CHENAB CANAL EAST CIRCLE				
FAISALABAD IRRIGATION DIVISION				
Kot Khuda Yar	56.5	67.9	124.4	82.1
Aminpur	25.4	63.0	88.4	77.3
HAFIZABAD IRRIGATION DIVISION				
Sangla	49.5	82.0	131.4	90.6
Uqbana	43.8	52.0	95.8	63.9
JHANG IRRIGATION DIVISION				
Dhaular	50.4	69.8	130.2	80.5
Veryam	32.5	53.3	85.8	67.8
Wer	35.9	59.0	94.9	100.0
LOWER CHENAB CANAL WEST CIRCLE				
UPPER GUGERA IRRIGATION DIVISION				
Chuharkana	65.2	71.6	136.9	96.9
Mohlan	70.2	67.9	[illegible]	95.0
Paccadala	46.4	67.3	113.7	92.6
LOWER GUGERA IRRIGATION DIVISION				
Buchiana	49.4	61.8	111.3	81.9
Tarkhani	[illegible]	54.9	[illegible]	82.0
Bhagat	46.9	53.7	100.6	95.7
BURALA IRRIGATION DIVISION				
Tandlianwala	52.7	95.4	[illegible]	95.6
Kanya	66.0	73.3	139.3	75.7
Sultanpur	81.2	83.9	165.1	69.0

Source: IIMI Survey Data 1996

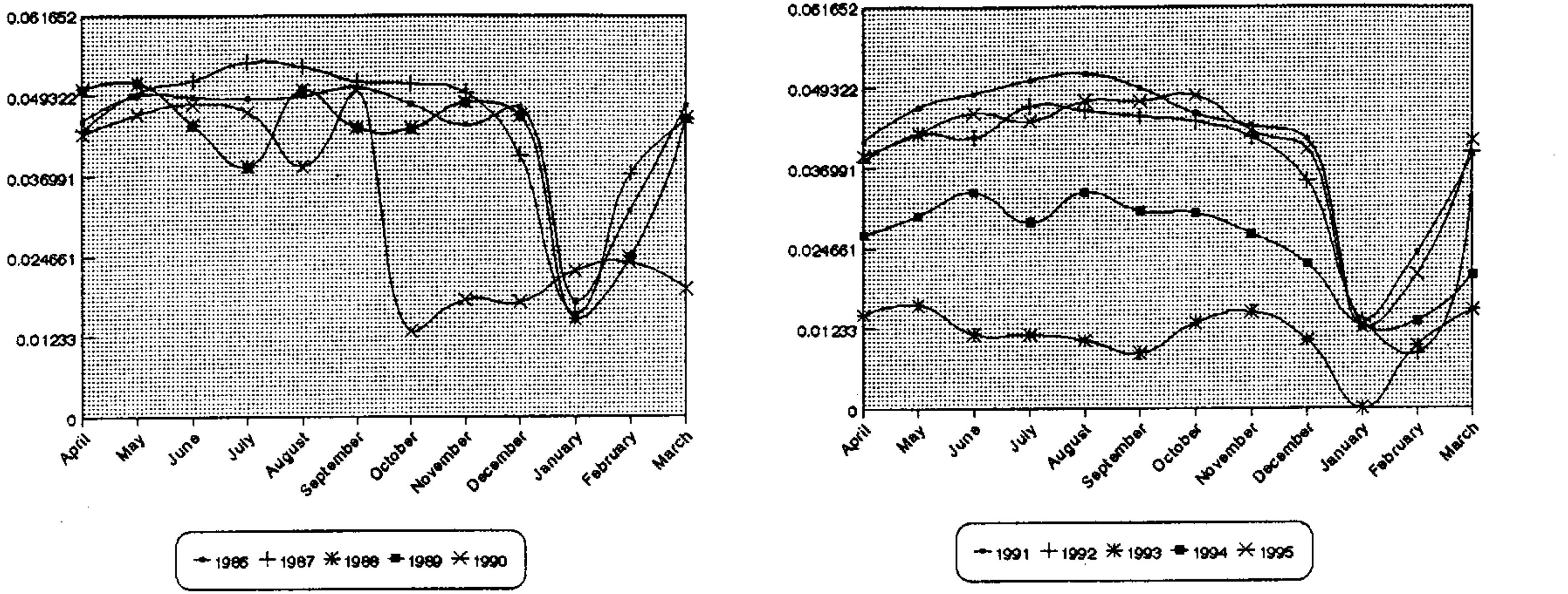
Figure 15 Administrative Units in the Lower Chenab Canal System, Rechna Doab, Punjab, Pakistan.



X-Axis: Months

Y-Axis: Volume in Mhm

Figure 16a Canal Allocations for the Jhang Branch of the LCC System in the Rechna Doab, Punjab, Pakistan.



X-Axis: Months

Y-Axis: Volume in Mhm

Figure 16b Canal Allocations for the Gugera Branch of the LCC System in the Rechna Doab, Punjab, Pakistan.

Canal have low variations that are sustained till a year after the Accord, while remaining below the peak of 1987. The drastic reductions experienced in the successive years of 1993 & 94 are reverted to near normal by 1995. In the Gugera Branch Canal, the drastic change in the late Kharif of 1990 is only temporary and followed by normal flows at the start of the next water year; however, its successive reductions in total allocations for the post-Accord period are nearly identical in magnitude and time to the situation explained earlier for the Jhang Branch Canal.

For the commands in Upper Rechna, the allocative comparisons for the pre- and post-Accord period provide distinct differences in both the UCC and the MR Link canals. For the UCC (Figure 17), much of the smoothness in allocations at the start and end of the Kharif seasons during the pre-Accord period has been replaced by an abruptness that has also affected the Rabi supplies to its perennial commands where allocations have been successively reduced over the same period of comparison. The M-R Link Canal has been the worst sufferer over the pre- and post Accord comparisons, whereby the reductions beyond 1991 have been sealed even below the 1986-88 low levels (Figure 18).

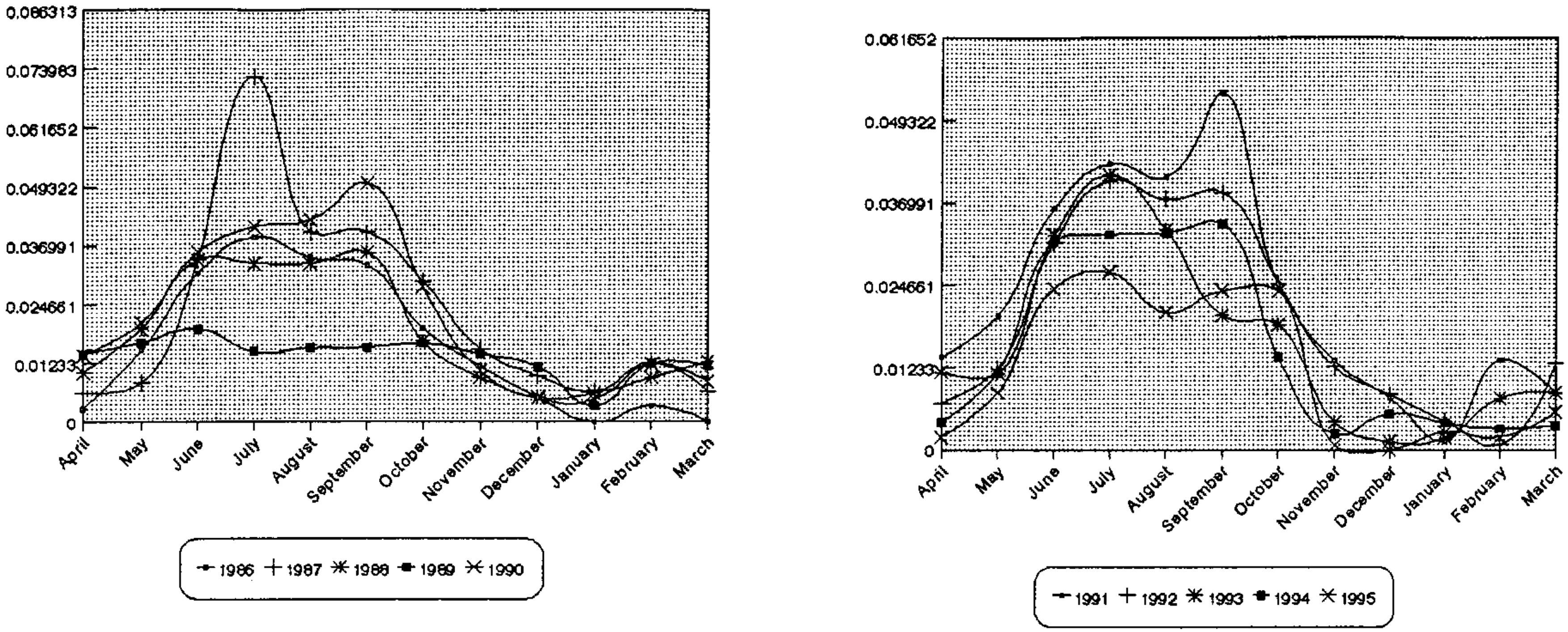
VIII. DEGRADATION OF LAND AND WATER RESOURCES

A. The Rise in Watertables

Waterlogging was first noticed in the upper region of the Rechna Doab a few years after opening of the Lower Chenab Canal in 1892. At that time, the watertable in other parts of the doab was fairly deep and irrigation applications were quite adequate for crops and for leaching requirements of the soil. Action aimed at solving the problems of waterlogging and salinity started in 1908 when the Punjab Government initiated investigations along the Upper Bari Doab Canal. Following this, a Waterlogging Board was established in 1912 to review progress made in eradicating the menace. In 1917, a Provincial Drainage Board was established to investigate the causes and effects of the problems and to suggest remedies. The Board was split in 1925 into the Waterlogging Inquiry Committee and the Rural Sanitary Board with the aim of improving the functions of the Board. In 1928, the Inquiry Committee was abolished, and a new Waterlogging Board created. Despite these administrative arrangements, the British never seriously addressed this issue. They found it cheaper and more profitable to expand the system rather than embark on major efforts to solve problems.

During the period 1912-52, various works were carried out in an attempt to solve the problem. These included:

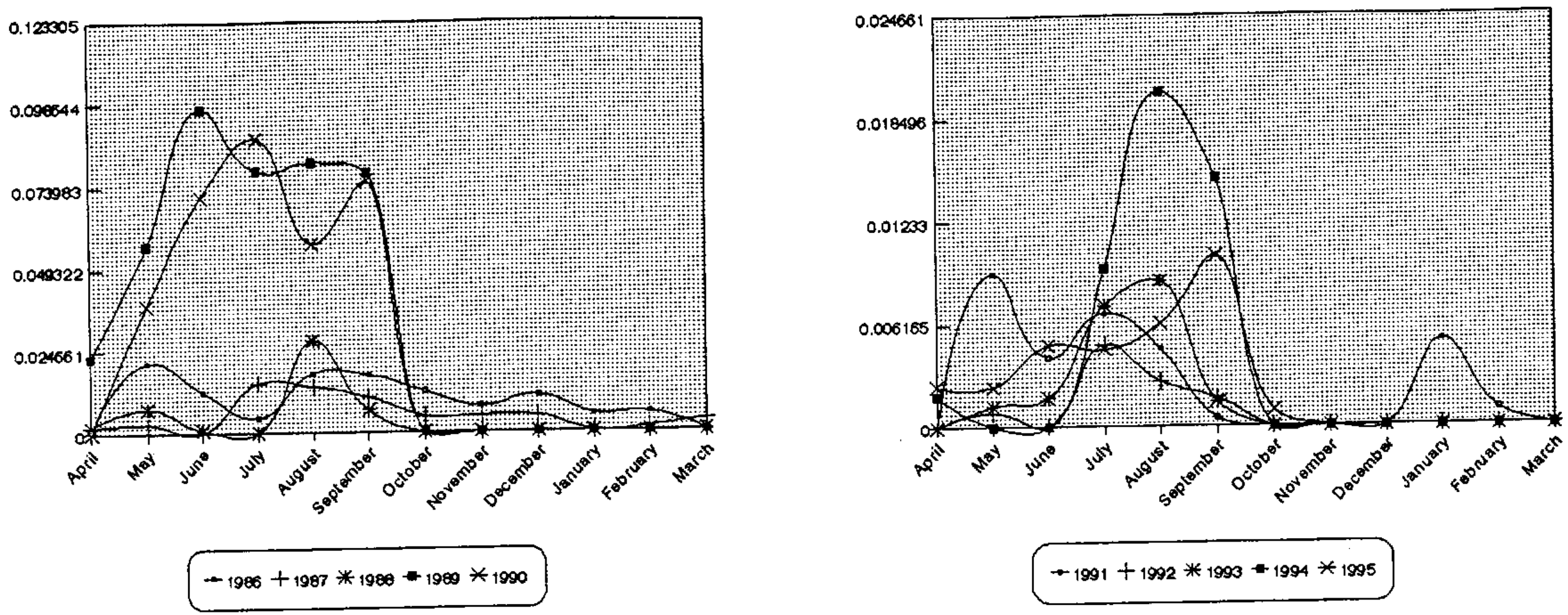
- frequent and extensive canal closures;
- lowering of canal water full supply levels;



X-Axis: Months

Y-Axis: Volume in Mhm

Figure 17 Canal Allocations for the Upper Chenab Canal System in the Rechna Doab, Punjab, Pakistan.



X-Axis: Months

Y-Axis: Volume in Mhm

Figure 18 Canal Allocations for the M-R Link (Internal) in the Rechna Doab, Punjab, Pakistan.

- conversion of areas from perennial to non-perennial irrigation;
- lining of canals;
- planting of eucalyptus groves;
- reclamation of rice cultivation; and
- limited use of open surface drains.

Attempts were also made to control the watertable by intercepting seepage from canals through drains and tubewells parallel to canals. The first such attempt was along the Lower Jhelum Canal, however these measures were not effective in controlling rising water levels. The tubewell pumping schemes implemented by the Punjab Irrigation Department between 1945-51 to eradicate waterlogging and to supplement the irrigation water were mostly based on inadequate data and not commensurate with the magnitude of the problem, with the result that they had no significance effect. The first such project was the Rasul Tubewell Scheme with 1526 units installed in the Rechna Doab.

Large scale construction for stormwater drains was initiated in 1933 and by 1947, 3700 kms of surface drains had been laid out mostly in Rechna and Chaj doabs. The Ahmadpur and the Kot Nikka open drains were the first in a series of open drains constructed for the Rechna Doab to complement the surface irrigation network under the Upper Chenab Canal (UCC) and Lower Chenab Canal (LCC) (locations provided under an updated map of drainage for the Rechna Doab are shown in Figure 19). Before partition, the UCC had 611,500 ha of land drained by 1217 km of drains, and the corresponding figures for LCC were 1.5 Mha and 1329 km.

As lack of maintenance put a damper on drain construction, lining of existing canals was initiated to reduce the seepage. In 1943, the lining of a portion of the Jhang Branch Canal was undertaken. This presented many difficulties and did not prove very successful. Further lining of existing canals were not undertaken. However, many new canals were lined such as the Ravi-Bedian-Dipalpur Link Canal, Balloki-Sulemanki Link Canal and Haveli Canal. Recharge to the aquifer was principally influent seepage from the rivers and to a lesser degree precipitation. It was equal to the natural discharge of groundwater by evapotranspiration and subsurface flow. Under the conditions that prevailed, dynamic equillibrium had been established between all the various componenets of recharge, discharge, and groundwater storage. Seepage from the Chenab and Ravi rivers generally moved towards the center of the doab where the portion unutilized against the ET losses progressed in a southwesterly direction of subterranean slopes. Prior to canal construction, the watertable occurred at a depth of more than 10 meters, and in the center of the Doab at more than 30 meters. Because of the relatively flat topography, low hydraulic gradient, and generally poor drainage conditions, the watertables began to rise due to increased recharge through unlined irrigation channel and deep percolation from croplands.

Simultaneously, with the rise of the watertable, the hydraulic gradient and consequent movement of groundwater towards the center of the doab decreased annually. By 1930, the

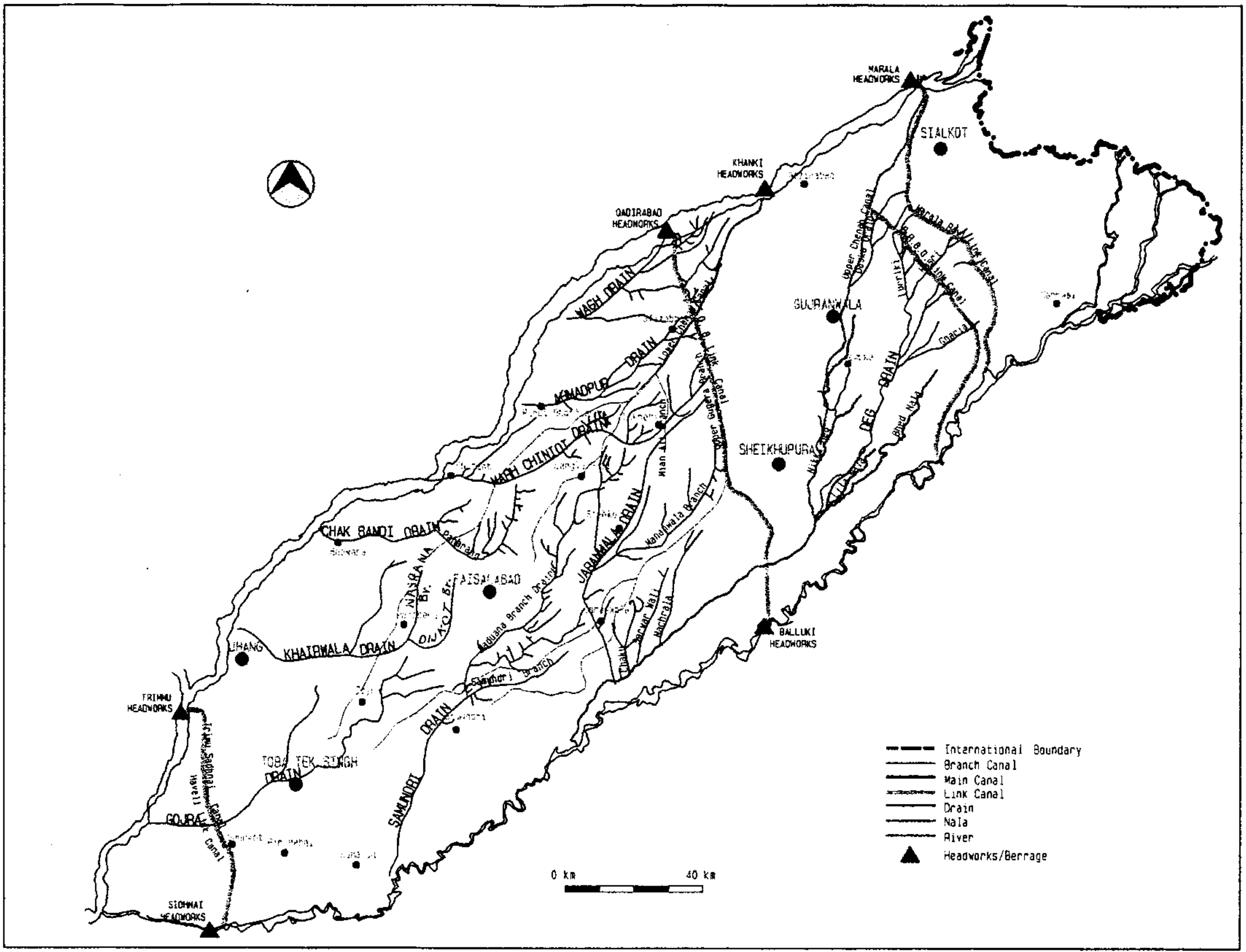


Figure 19 Layout of Drainage Network in Rechna Doab, Punjab, Pakistan.

watertable in the center of the doab had risen above the altitude of the adjacent rivers, thereby reversing the hydraulic gradient and direction of groundwater flow. By 1960, the watertable had risen as much as 30 meters in the area southeast of Faisalabad, and in many others it reached the land surface.

B. Incidence of Salinity

The problem of soil salinity came to the notice of the Punjab Government as early as 1927 in the upper regions of Rechna Doab where the ground watertable was either at the surface or quite near to it. The extent of the damaged area was estimated through a salinity survey (Thur Girdawari) started by the Waterlogging Enquiry Committee during that year. It was initially confined only to areas where the watertable was within 1.5 meters from the ground surface. Following investigations in 1937, the presence of salinity in deep watertable areas was established as well.

As a result of these findings, the Thur Girdawari work was taken up by the Irrigation Department and extended to the entire irrigated area with varying watertable depths in the Punjab region in 1943 and subsequently to all of the four provinces of Pakistan in 1960. Only in the case of 'Thur Girdwari' is there a time series record available for establishing how the salinity situation may be changing with time (Table 14). From a gross point of view, these figures can be taken to represent, in general terms, the trends in soil salinity.

Salinity was attributed to high watertable conditions and groundwater as the source of salts. The earliest salinity surveys, in 1927, were therefore confined only to areas where the watertable was within five feet of the ground surface. Later, investigations conducted in 1937 revealed that salts were originally present in the soil crust, and their movement was accelerated to the surface by high watertables and inadequate irrigation applications. By 1943, the survey was extended to the entire irrigated area with varying watertable depths in the Punjab region.

C. Land Reclamation Initiatives

Following the establishment of a Land Reclamation Board in 1940, reclamation activities have been carried out in Punjab regularly since 1942. In 1952, a Soil Reclamation Board was set up and given wide statutary powers to implement reclamation schemes. The schemes included Chuharkana, Jaranwala, Chichoki Mallian, and Pindi Bhattian for a total of 48,000 ha in the Rechna Doab. Within these schemes, 190 project wells were constructed and placed in operation between 1954-60. These schemes were later incorporated into SCARP-I which was the first of the planned watertable control projects in the country. A tubewell scheme between Sheikhupra and UCC was also completed. Adaptive research at Chukanwali and Jaranwala field experimental stations (Table 15) was subsequently replicated at the farmers' fields for leaching of the root zone and growing of suitable crops. Targeted

Table 14. Reclamation Operations and Area Reclaimed in Punjab

Year	Reclamation supply actually utilized (cusecs)	Area operated in acres	Area reclaimed during the year (acres)	Area reclaimed upto date in acres
Area Reclaimed upto 1947-48				143046
1948-49	2254.48	102347	25164	168210
1949-50	2345.79	107921	19437	187647
1950-51	2107.55	96897	20195	207842
1951-52	2161.35	103113	17644	225486
1952-53	2624.14	128979	14798	240284
1953-54	4142.97	179172	26827	267111
1954-55	4004.77	169066	27841	294952
1955-56	3498.92	153148	34383	329335
1956-57	3156.44	150766	23901	353236
1957-58	3040.59	140903	27843	381079
1958-59	3090.25	152807	37067	418146
1959-60	2547.90	127355	27251	445397
1960-61	2407.84	121258	38507	483904
1961-62	2106.88	99872	21912	505816
1962-63	2019.38	96788	21801	527617
1963-64	2239.84	106143	31468	559085
1964-65	2350.05	113018	27621	586706
1965-66	2704.22	128840	29230	615936
1966-67	2561.00	125592	34596	650532
1967-68	2679.81	130399	36144	686676
1968-69	2825.05	133636	28206	714882
1969-70	2329.93	116794	37738	752620
1970-71	1979.75	97319	36087	788707
1971-72	1862.29	91090	21387	810094
1972-73	1853.51	90838	30249	840343
1973-74	2040.41	96313	33689	874032
1974-75	2088.13	100418	20247	894279
1975-76	2082.20	97689	34563	928842
1976-77	2159.45	101529	38132	966974
1977-78	2161.74	101618	20931	987905
1978-79	2320.05	109828	38515	1026420
1979-80	1902.08	88552	42739	1069159
1980-81	1465.89	69806	22575	1091734
1981-82	1216.36	62383	15465	1107199
1982-83	1037.82	55682	25284	1132483
1983-84	823.40	39505	18451	1150934
1984-85	805.80	37944	10092	1161026
1985-86	860.12	42738	8514	1169540
1986-87	1015.16	48866	16362	1185902
1987-88	1118.62	51992	14007	1199409
1988-89	984.96	47170	17219	1217128
1989-90	1074.63	46270	16426	1233552
1990-91	973.96	45774	12998	1246550

Source : Directorate of Land Reclamation,
Punjab Irrigation and Power Department, Lahore.

Table 15. Experimental Research Stations in the Rechna Doab, Punjab, Pakistan.

S.No.	Name of Research Station	Location	Area (ha)	Year of start	Description
1	Chukanwali	Near Hafizabad Dist. Gujranwala	1475.1	1926	Represents high watertable conditions. Field drainage of different types have been tried.
2	Mohranwala	Near Jaranwala Dist. Faisalabad	20.485	1939	Represents the rising watertable area. Method of reclaiming saline soils have been tried.
3	Jagattan	Near Jaranwala Dist. Faisalabad	24.196	1952	Represents deteriorated land in respect of salinity and waterlogging.
4	Haveli	Near Shorkot Cant. Dist. Jhang	130.865	1945	Represents saline sodic conditions of Ghag Garkhana Blocks of Haveli canal.

Table 16. Salient Feature of SCARPs in Rechna Doab, Punjab, Pakistan.

SCARPs	Year of Construction	Gross Area (Mha)	CCA (Mha)	SCOPE		
				Tubewells		Drains
				Fresh Groundwater (No.)	Saline Groundwater (No.)	Surface (Km)
SUB-SURFACE DRAINAGE PROJECTS						
SCARP-I	1960-63	0.4925	0.4617	2069		
SCARP-IV Muridke & Mangtanwala	1969-73	0.2258	0.2242	935		
SCARP-V Shorkot Kamalia Pilot Project	1975-77	0.0683	0.0623	101		
SCARP-V Paharang Drain	1976-80	0.097	0.095	NIL		84
Satiana Pilot Project	1975-77	0.047		69		
Khairwala Unit	1981-87	0.134				
Gojra Khewra Phase-I	1987-89	0.015				
Gojra Khewra Phase-II	1989-93	0.17685	0.14164		58	296
Shorkot Kamalia (Saline)	1989-94	0.02266	0.02185		222	257
Lower Rechna (Drainage-IV)	1983-93	0.05261	0.04411			615
Upper Rechna (Deg Unit)	1990-95	0.18940	0.12626			60

lands were the ones either partially affected by salinity, or recently gone out of cultivation, and those never cultivated because of salinity.

For the first category of land, efforts were confined to the Government lands or to the estates of big landlords where it was possible to provide separate outlets for reclamation supplies. Later, it was decided that reclamation should also be extended to such areas where land belonging to small farmers had been damaged by salinity. Such supplies for reclamation could only be made available during excess summer flows. Under this program, over 450,000 ha. have been reclaimed in the Punjab since independence.

For the second category, biological methods were developed at the research stations. Saline-sodic land was allotted to volunteer farmers who could acquire proprietary rights for half the lands after reclamation, which usually took six to eight years.

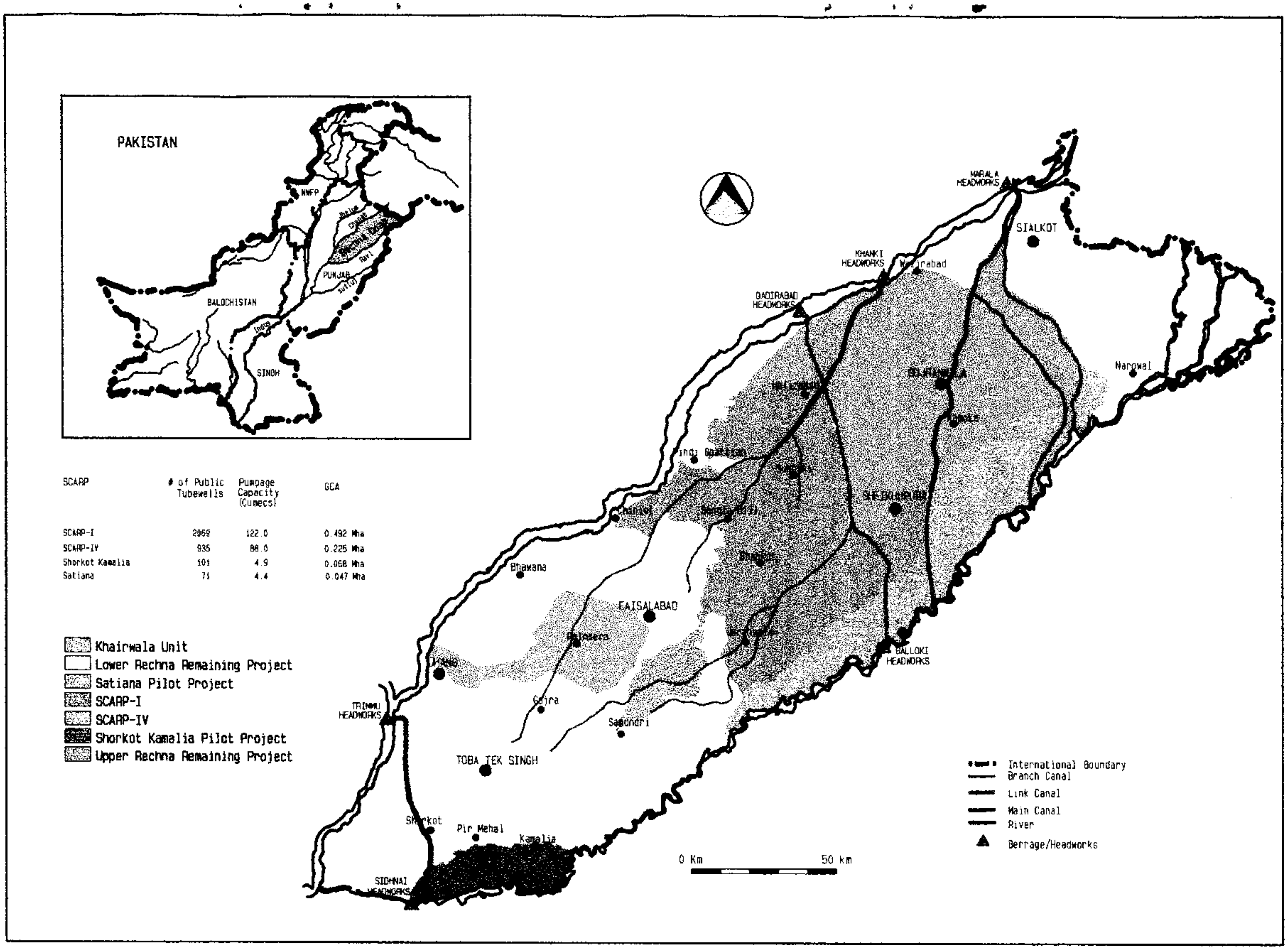
No provision of drainage was made for the undertaking of reclamation operations stated under the two categories of the lands mentioned above, as these were conducted in deep watertable areas only (outside SCARPs). These were thus termed as temporally relief measures, as the land once reclaimed could face deterioration with the passage of time if inadequate preventive measures were not taken to keep it in a fit condition.

IX. DEVELOPMENT OF SCARPS

A. Scope of Operations

The details on the emergent priorities for land reclamation and the structural adjustments to this effect have already been provided in the previous sections. After assuming the mantle for the land reclamation mandate, WAPDA initiated its capital intensive operations with the planning for 18 schemes within the country, with adjuncts of a systematic approach in data collection and monitoring inherited from the defunct WASID. Much of the basic work in this respect had already been initiated/completed under WASID investigations for soil texture, salinity, and groundwater quality. For the Rechna Doab, there were three major reclamation schemes planned from the outset (see Figure 20):

1. Areas in the center of the doab, bracketed with the very first initiative under SCARPs. It was primarily a vertical drainage scheme on 0.492 Mha of gross area. The objective was lowering of the watertables and utilization of the FGW pumpage as an additional source of irrigation supplies. A total of 2069 tubewells of varying capacity were installed between 1960-63 for a cumulative discharge volume of 0.2 Mhm per year.



SCARP	# of Public Tubewells	Pumpage Capacity (Cumecs)	GCA
SCARP-I	2069	122.0	0.492 Mha
SCARP-IV	935	88.0	0.225 Mha
Shorkot Kamalia	101	4.9	0.068 Mha
Satiana	71	4.4	0.047 Mha

Figure 20 Salinity Control & Reclamation Projects (SCARPs) in the Rechna Doab, Punjab, Pakistan

2. Upper Rechna, mainly comprising the districts of Gujranwala and Sheikhupura, both surface and vertical drainage had been planned for the areas comprising the present day SCARP-IV and Upper Rechna Remaining projects. Additionally, flood protection measures were also invoked for the MR Link and BRBD Link canals.

3. Lower Rechna, inclusive of, but not limited to, the present day reclamation schemes comprising SCARP-V, Khairwala, Satiana, Gojra Khewra, and Drainage IV (Faisalabad). The reclamation strategy for this area underwent several revisions since the original planning in the late 1960s; resultantly, pilot projects were initiated in selected areas to provide immediate relief against rising watertables.

B. Quantum of Gains

Pertinent details on the magnitude and scope of SCARP operations within Rechna Doab is provided in Table 16 (page 61). From the table, it becomes obvious that many of these reclamation programs involved tubewell drainage in both FGW and SGW areas of the doab. The targeted lowerings of the watertable relied on the prepumping records (dating back to 1905) that showed the watertable fluctuating by a couple of meters from season-to-season and from year-to-year. Because of these fluctuations, the average altitude of the watertable prior to full-scale pumping (and the areal extent and magnitude of decline in water level caused by subsequent pumping) could only be approximated. The altitude and shape of the watertable used as a reference for determining the annual and long term change in water level is based on the average water level in the 150 observation wells installed within the Rechna Doab at that time. Based on these benchmark observations, the area under various depths to watertable is listed in Table 17. Since the reclamation schemes are designed with the multiple objective of removing surface and profile salinity through reduction of capillary action transfer and increased availability of leaching fractions, the benchmark reporting for the same is also provided under (b) and (c) of Table 17.

If the appropriateness of the various SCARP schemes within Rechna Doab was judged solely on the basis of reduction in the watertables and extents of soil salinity, along with increased in cropping intensities, then this purpose seems to have been realized in comparison with the pre-project conditions. Figure 21 indicates the watertable fluctuations for both pre- and post monsoon periods in 1986 for the major SCARPs within the doab. In three of the four SCARPs, the watertable rise near the root zone was insignificant; however, for the Satiana Pilot Project (Figure 22), where much of the areal extent during the pre-monsoon dry season remains between 150-300 cm, the response to higher levels of recharge is quite noticeable. The Satiana Pilot Project, which had been described as a bath tub full of water by the expatriate consultants before the start of the Drainage IV project, has experienced subsequent reductions in watertables due to desilting of major drains and the installation of tile drainage in parts of the Drainage IV Schedule I site that overlaps with its boundary.

Table 17 (a) Area Under Various Depths to Watertable June/April (1959-64), Rechna Doab, Punjab, Pakistan.

Depth to Watertable % of the Area		
< 1.524 m	1.524-3.048 m	> 3.048 m
10.9	39.3	49.8

Table 17 (b) Occurrence of Surface Salinity as per WAPDA Salinity Classification (1962-63).

Percentage of Gross Area		
S1	S2 & S3	S4
66.0	24.0	8.0

Table 17 (c) Distribution of Profile Salinity as per WAPDA Salinity Classification (1962-63).

Bore Hole (No.)	Profiles Classification			
	NonSaline-NonSodic (%)	Saline (%)	Saline Sodic (%)	NonSaline-Sodic (%)
5498	39	3	32	26

Source: SMO

Table 18. Number of Tubewells by Design Capacity (lps).

Schemes	57	71	85	100	113	127	142
SCARP-I							
Total	331	403	543	218	266	61	6
SCARP-IV							
Muridke	72	-	159	-	175	-	217
Mangtanwala	11	-	56	-	106	-	138

Source: Arif (1993)

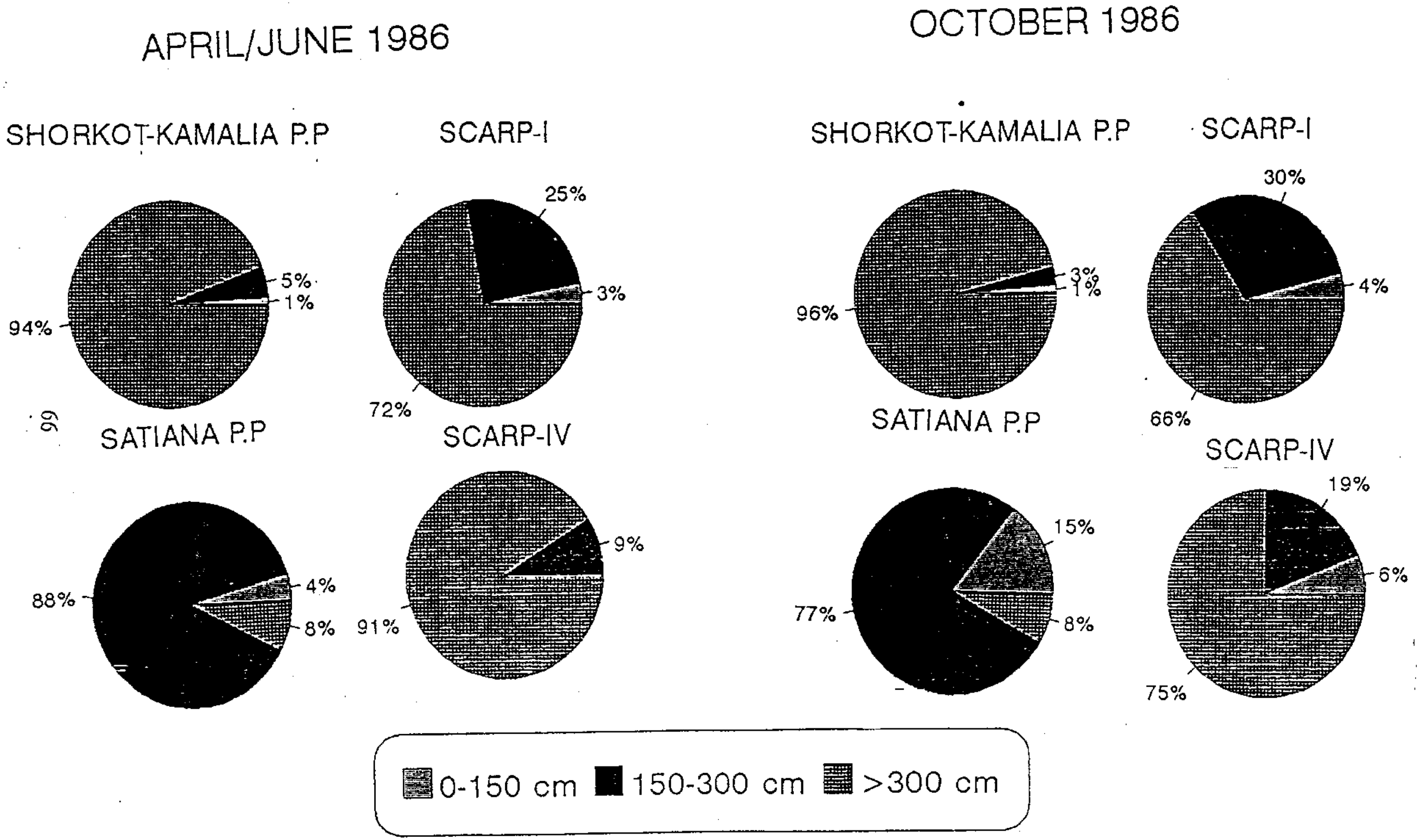


Figure 21 Seasonal Fluctuations in Depth to Watertable, Rechna Doab, 1986.

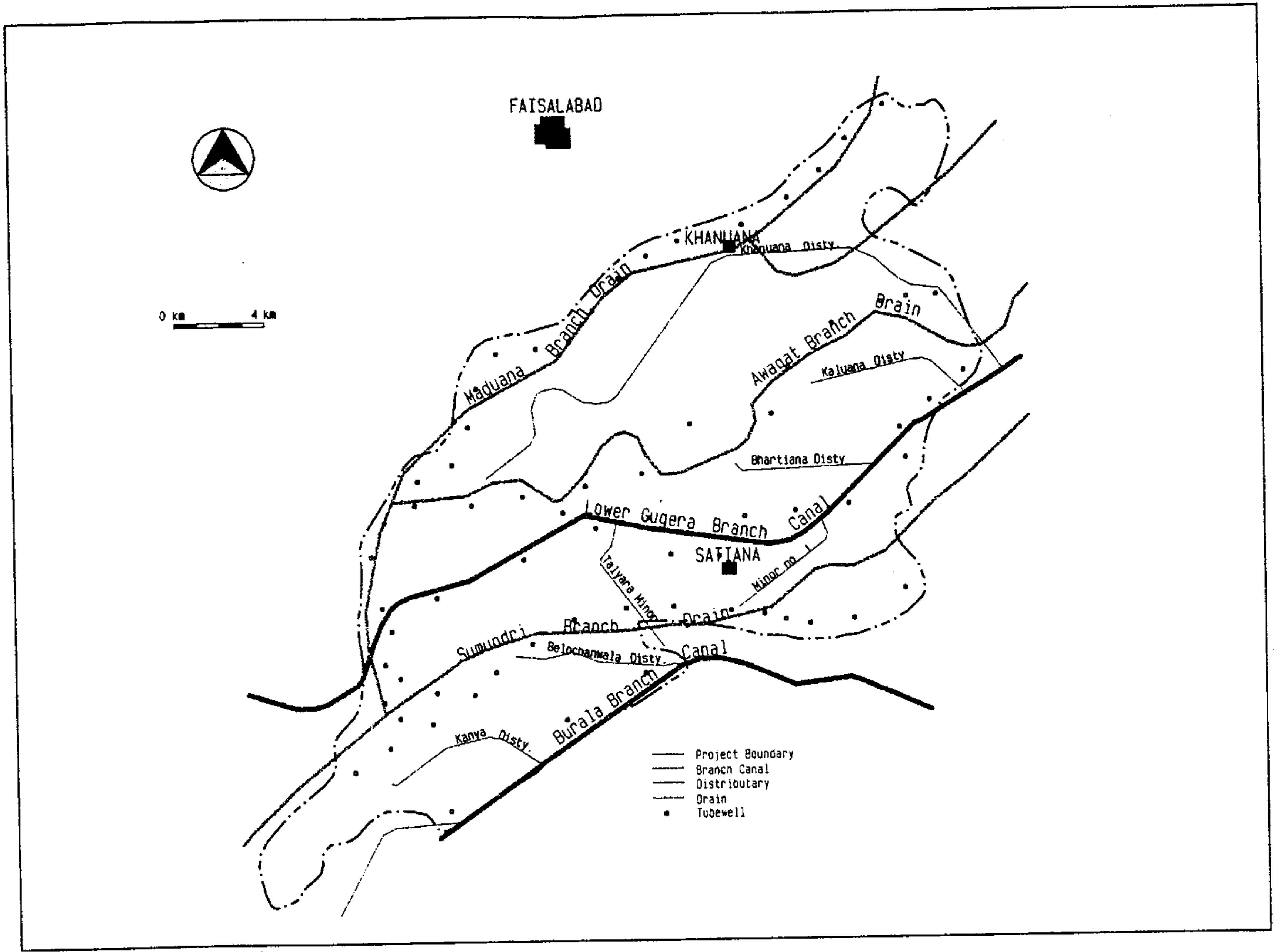


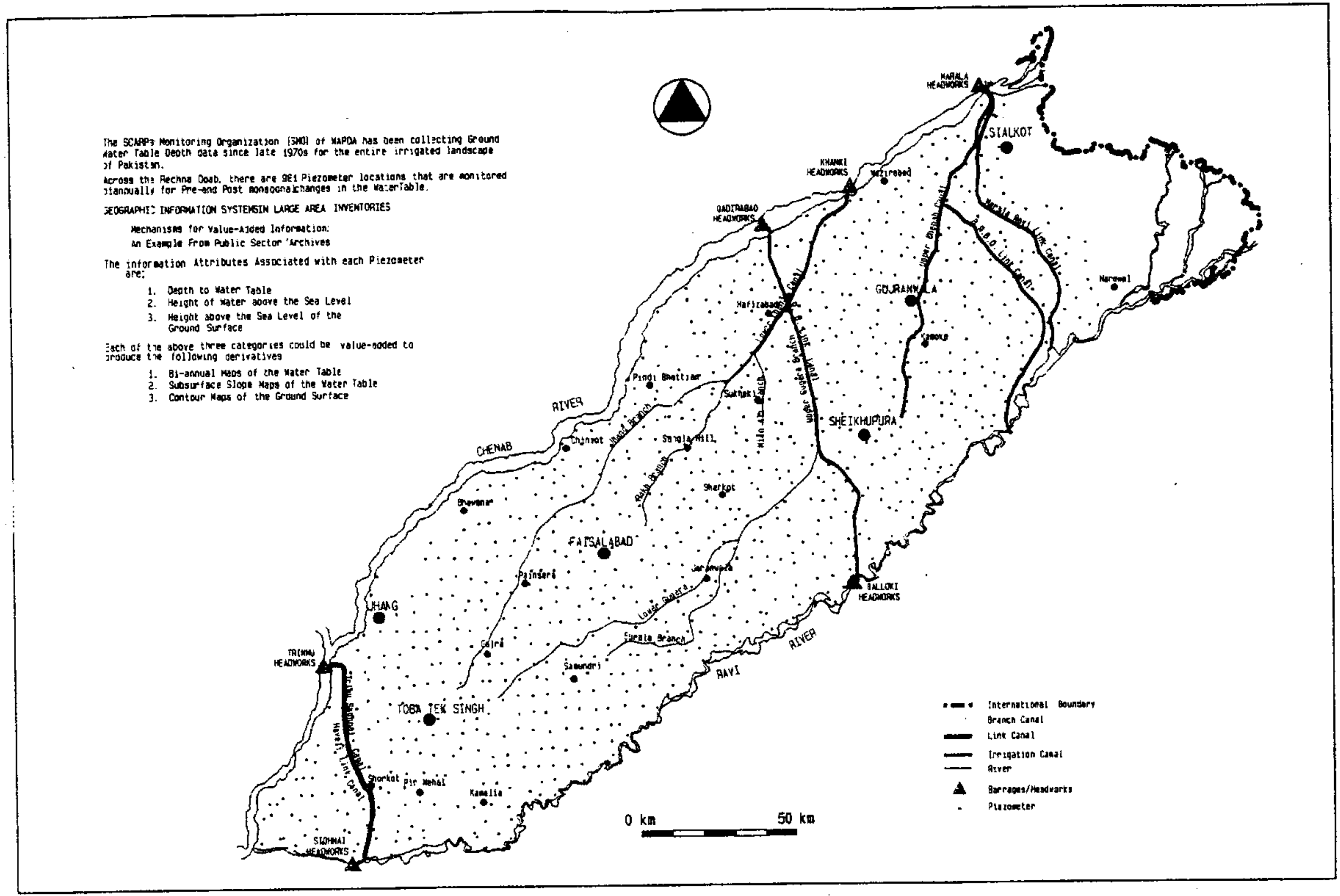
Figure 22 Satiana Pilot Project (Lower Rechna Remaining), Punjab, Pakistan.

By 1980, the major SCARP tubwells within the Rechna Doab had completed several years of operational life in pumpage assisted watertable reduction. The time period thereonwards affords useful insights into the long term evaluation of the vertical drainage strategy adopted by WAPDA. Based on the monitoring through 981 piezometers installed by the SMO, WAPDA, across the entire Rechna Doab (Figure 23), the watertable levels in reference to monsoonal activity between 1980-93 are presented in Figure 24. Considering the "disaster" definition of WAPDA, the temporal comparison indicates a one time situation in the post-monsoonal period of 1980 when the watertables had risen to within the root zone in the head reaches of the LCC and the tail commands of the Nokhar Branch Canal (UCC system). Other than this isolated occurrence, the recorded instances of high water levels are too sparse to assume significance (tail reach of the Nokhar Branch Canal in Oct. 1985 & 93). The most dominant mapped classifications are below 150 cm (predominantly > 300 cm), thereby indicating no perceivable threats to drainability of the root zone.

Similarly, in comparison to soil salinity assessments made by WASID during 1953-65, WAPDA's MPR survey data for the entire Rechna Doab indicates a total reduction in salinized extent by 11% (Figure 25), much of it across the slightly salinized regimes which usually constitutes the first priority against reclamation gains. Since the MPR survey was the most thorough assessment of salinity extent, the spatial distribution patterns for the same indicate a hybrid pattern of both small and large patches scattered across most of the doab. Figure 26, an aggregate of all salinity classes for comparison against non-saline land, shows profile salinity to be not as numerous as its surface counterpart which predominates in the commands of Upper Chenab, LCC Main, Lower Gugera, Haveli, and Koranga Feeder Canals. A more descriptive assessment of this salinity at the irrigation sub-division level is provided in Volume Seven of this report.

C. Agricultural Redemptions

Coincident with the abovementioned gains is an increase in the cropping intensity and agricultural productivity. While the increase in the former is all too obvious in lieu of the foregoing, concerns would be more valid towards long term sustainability of the same. From Figure 27, where temporal reference to changes in the cropping intensity has been made after substantial operational experience in SCARPs, the incremental trends are somewhat sharper for the newer SCARPs in comparison to SCARP-I, but not in magnitude of the parameter which is primarily due to the very high density of private tubewells in areas comprising SCARP-I. Suffice to say, while the farmers in SCARP-I have had a head start in tubewell development, the actual use of the resource is limited to meeting the high consumptive use on existing CCA rather than extensions elsewhere within the GCA. This can be grasped from the fact that in reference to the time period for the reporting on changes to cropping intensity above, SCARP-I had 90% of the land under non-saline to slightly saline category which was much more than the corresponding figures of 77% and 83% for SCARPs IV & V, respectively (Figure 28). The contextual reference to the development of the tubewells will be made separately after the discussion on SCARPs.



The SCARPs Monitoring Organization (SMO) of WAPDA has been collecting Ground Water Table Depth data since late 1970s for the entire irrigated landscape of Pakistan.

Across the Rechna Doab, there are 981 Piezometer locations that are monitored biannually for Pre-and Post monsoonalchanges in the WaterTable.

GEOGRAPHIC INFORMATION SYSTEMSIN LARGE AREA INVENTORIES

Mechanisms for Value-Added Information:

An Example From Public Sector 'Archives

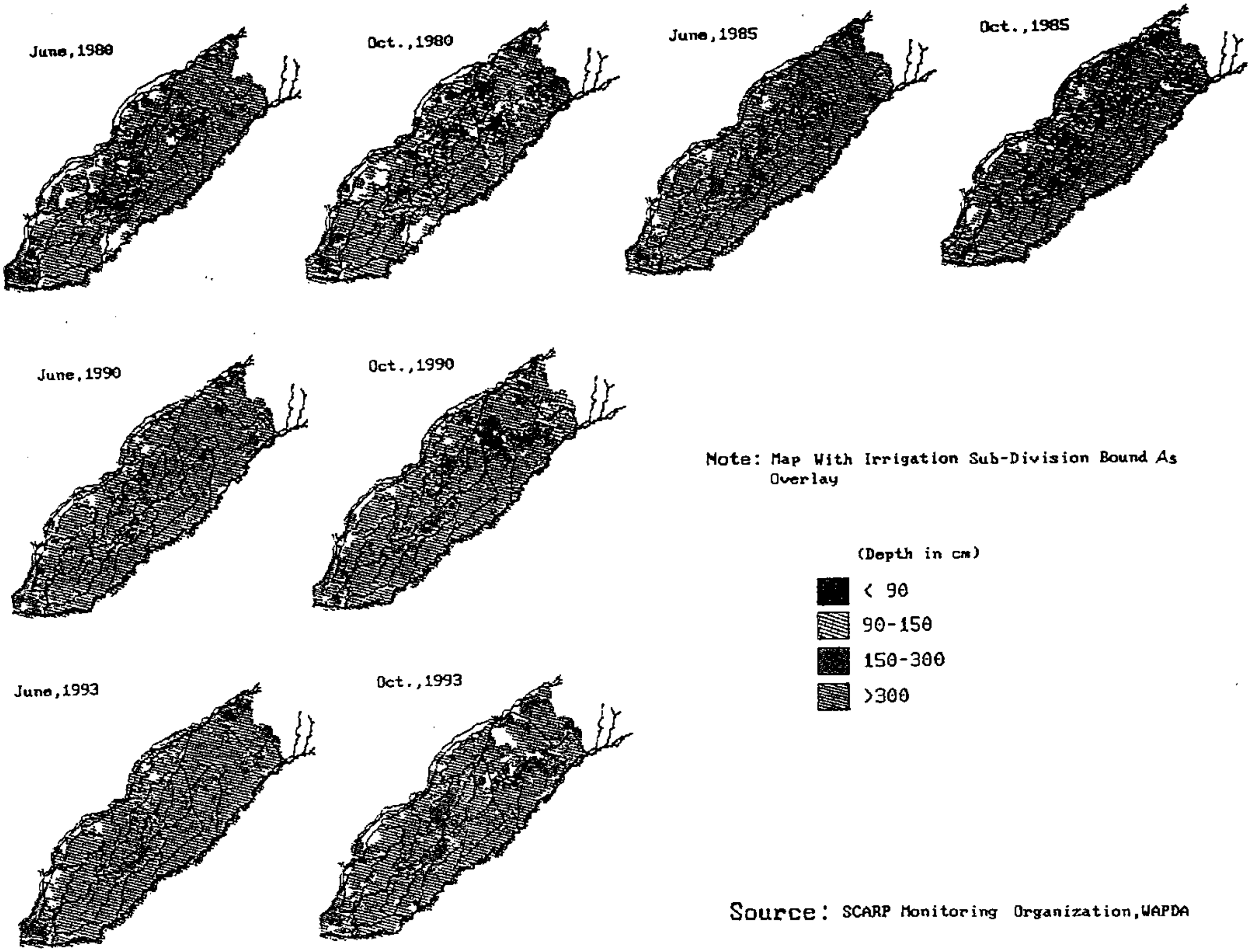
The information Attributes Associated with each Piezometer are;

1. Depth to Water Table
2. Height of Water above the Sea Level
3. Height above the Sea Level of the Ground Surface

Each of the above three categories could be value-added to produce the following derivatives

1. Bi-annual Maps of the Water Table
2. Subsurface Slope Maps of the Water Table
3. Contour Maps of the Ground Surface

Figure 23 Location Map of Piezometers Installed by SMO (WAPDA) across the Rechna Doab, Punjab, Pakistan.



Note: Map With Irrigation Sub-Division Bound As Overlay

Source: SCARP Monitoring Organization, WAPDA

Figure 24 Temporal Change in Seasonal Fluctuations of Depth to Watertable in the Rechna Doab, Punjab, Pakistan.

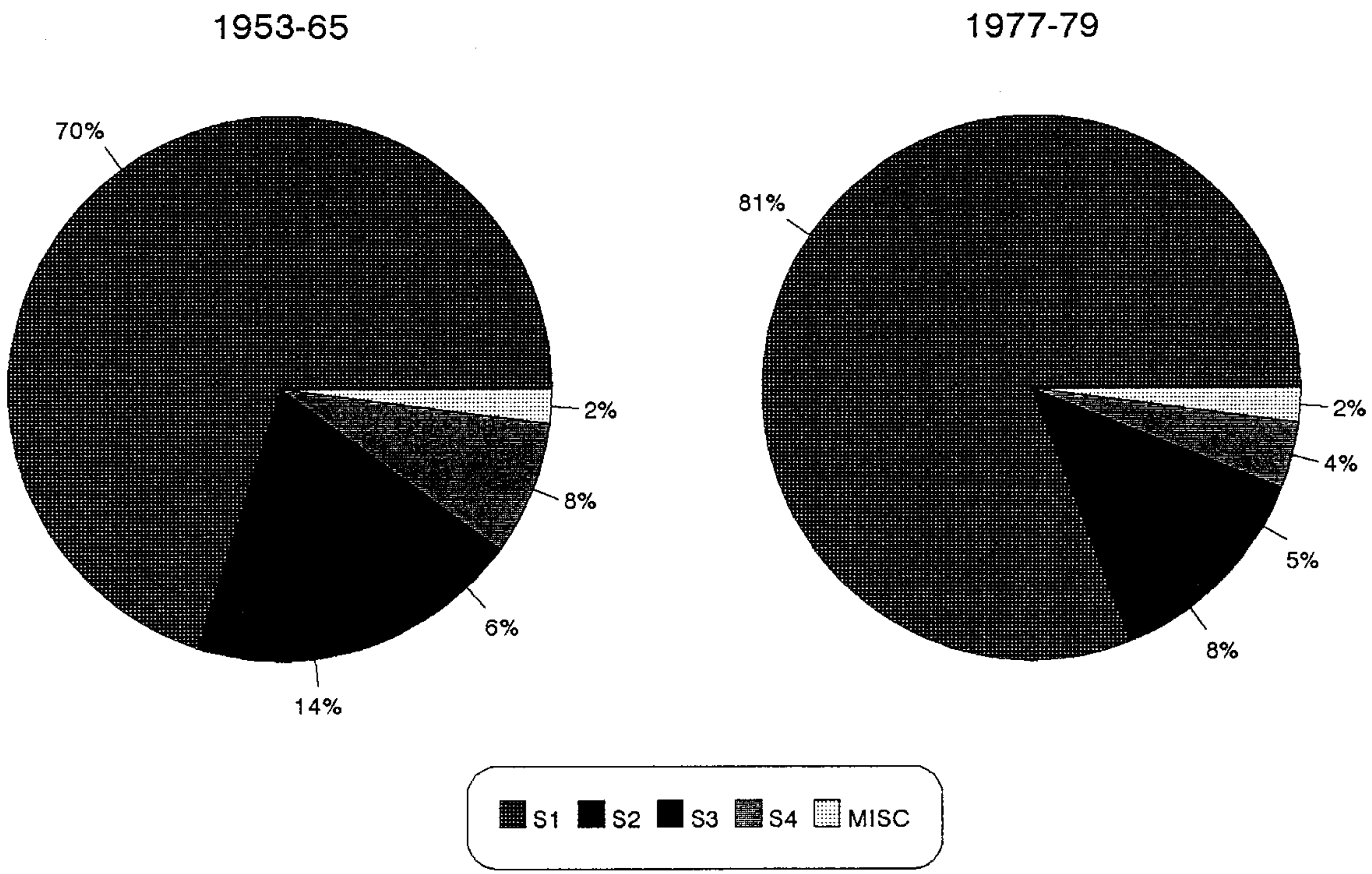
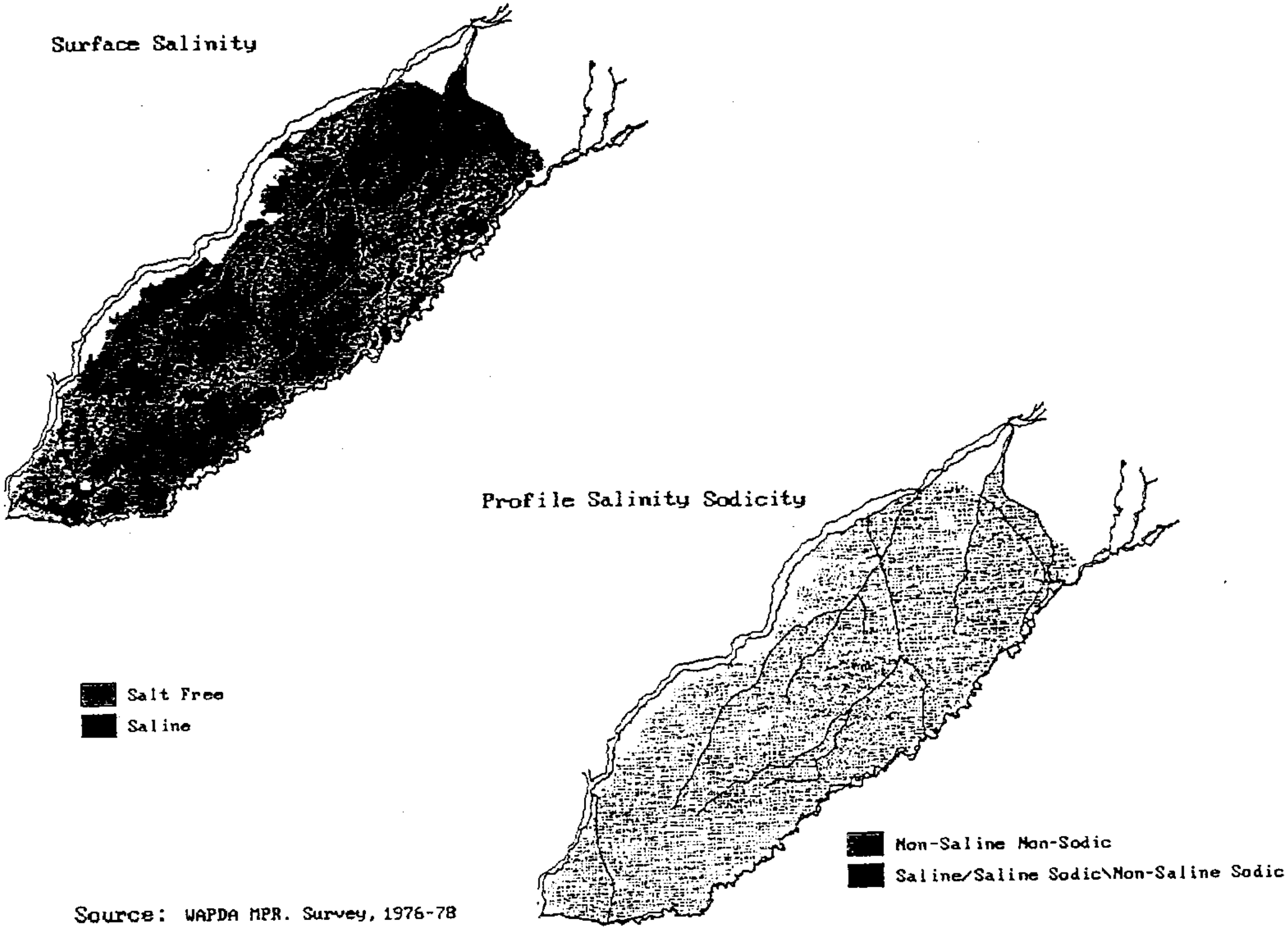


Figure 25 Comparison of the Soil Salinity Investigations by WASID (1958-65) and WAPDA MPR Survey (1977-79) in Rechna Doab, Punjab, Pakistan.



Source: WAPDA MPR. Survey, 1976-78

Figure 26 Aggregate Level of Surface and Profile Salinity in the Rechna Doab, Punjab, Pakistan.

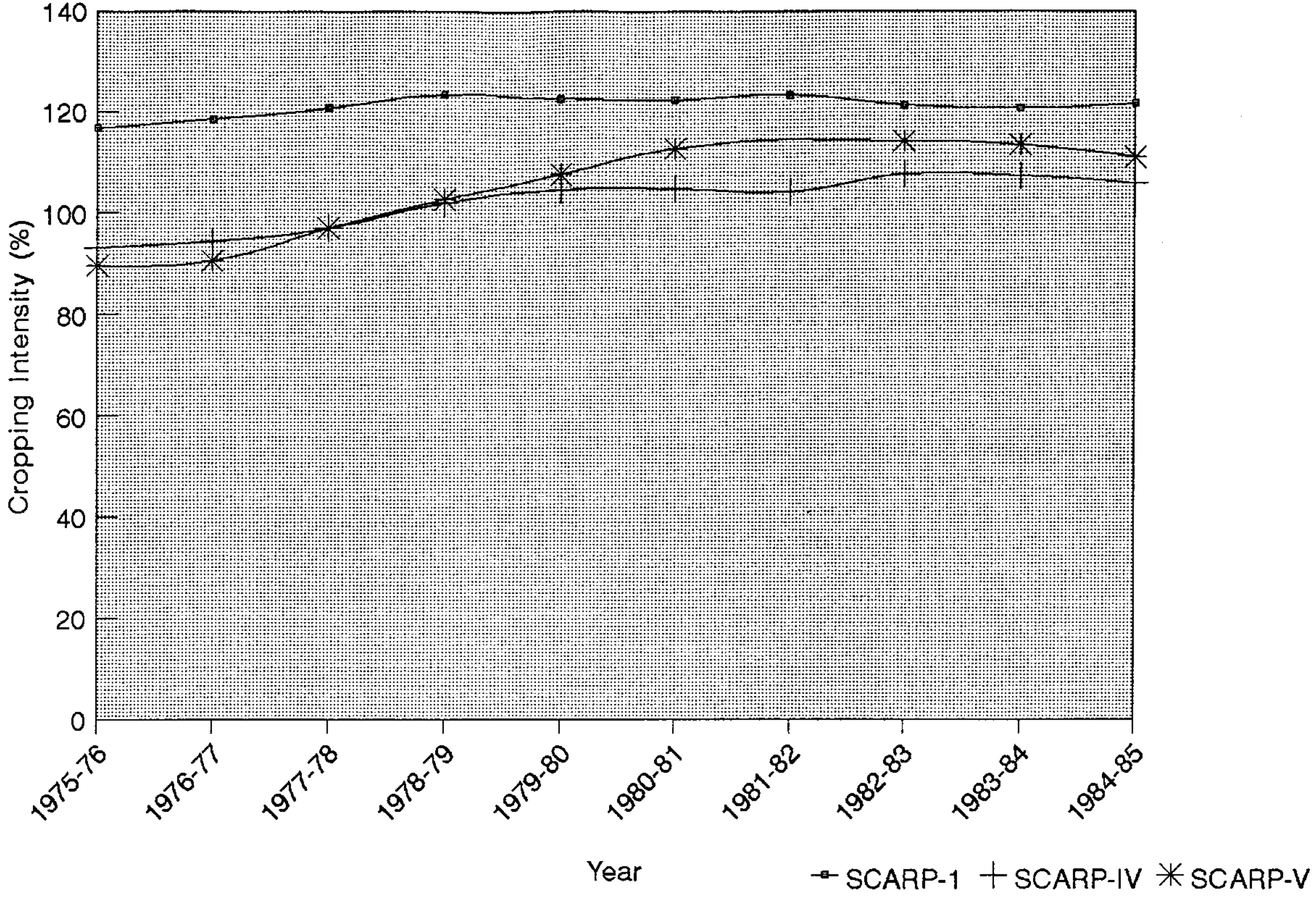
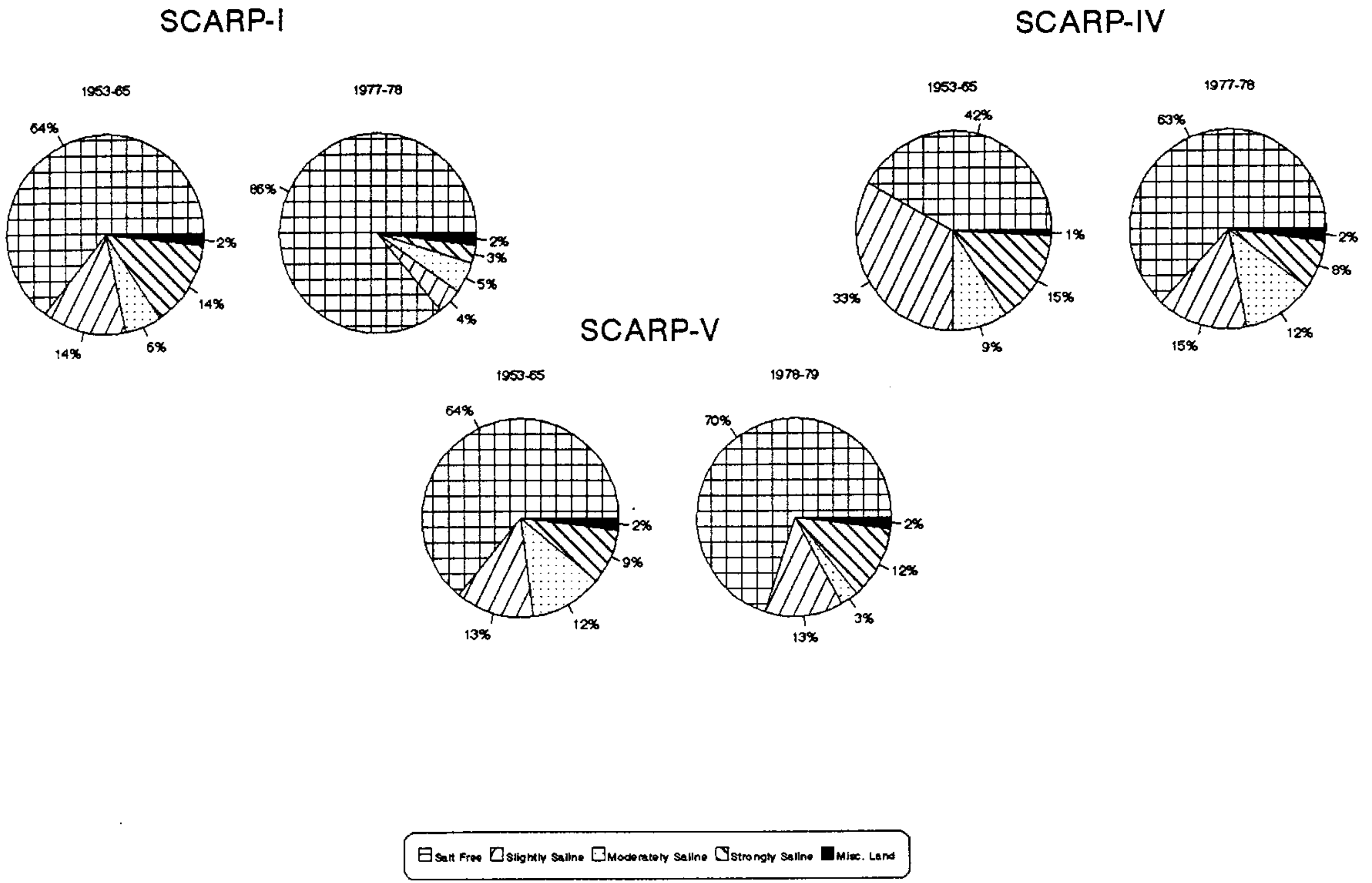


Figure 27 Cropping Intensity in the SCARP Areas of Rechna Doab, Punjab, Pakistan.



Source: Salinity and Reclamation Planning Division, WAPDA

Figure 28 Surface Salinity in SCARP Areas of Rechna Doab, Punjab, Pakistan.

In contrast to the intensity gains above, the yields of major crops within the SCARPs have not shown sustained patterns of growth. Notwithstanding assumptions of incremental returns to yield at the time of project planning, a necessary prerequisite to benefit/cost projections, judgements anchored solely to land reclamation as the panacea for all deficiencies are likely to suffer from misconceptions. For all practical purposes, reclamation is only an exercise to make additional land available for crop growth and not an instrument to effect gains in yield. From Figure 29, the most dominant inference casts a shadow of doubt on the potential of agricultural growth in areas that are reaching the limits of extensive growth aided by public sector reclamation schemes. The most recent of the three reclamation schemes, SCARP-V, with higher flexibility for extensive gains through the yet to be completed Shorkot Kamalia (Saline) Project, shows a considerable jump in the yields of cotton, rice, and wheat crops after a sag interval in 1983-84; elsewhere, there have been no improvements in these crops since the start of the 80s decade.

A point of interest would be to know the impact of changes in crop intensity and yield within SCARPs in relation to the macro-level agricultural growth figures like area and production across the larger divide of the Rechna Doab. Outside WAPDA, the agricultural reporting in Punjab is done by the Provincial Agriculture Department (PAD). The data aggregation is accomplished across districts, which are the middle order civil administrative and revenue units. Since the boundaries of these districts overlap with the WAPDA Projects, comparisons within Rechna Doab would approximate the following:

District(s) of Sheikhupura & Faisalabad	SCARP-I
Jhang & Toba Tek Singh	SCARP-V
Sheikhupura	SCARP-IV

Based on the set of graphs appearing under Figs. 30-33, the following may be deduced in terms of areal and production changes associated with major crops within the selected revenue districts of the Rechna Doab.

Portions of District Faisalabad constitute the southern part of SCARP-I where the area and production trends of major crops reached a lower order of stability in the early 1980s. In fact, cotton is the most significant sufferer for which the downslide had started a decade earlier; however, somewhat ironically, in comparison with other crops for which the negative growth in area and production has not been reversed or improved substantially, cotton showed a remarkable reversal as a result of the gains made through the Schedule-II of the Fourth Drainage Project aimed at lowering of the watertable. By the early 1990s, record production levels had been achieved for this crop; however, the latest situation does not augur well towards increasing agricultural realizations within the district as a whole.

For the Sheikhupura District, comprising much of the northern part of SCARP-I and SCARP-IV, cotton is steadily disappearing in what is increasingly becoming a high consumptive use environment for crops like rice and sugarcane. For rice especially, after steady increases in both area and production, there are indications that production levels

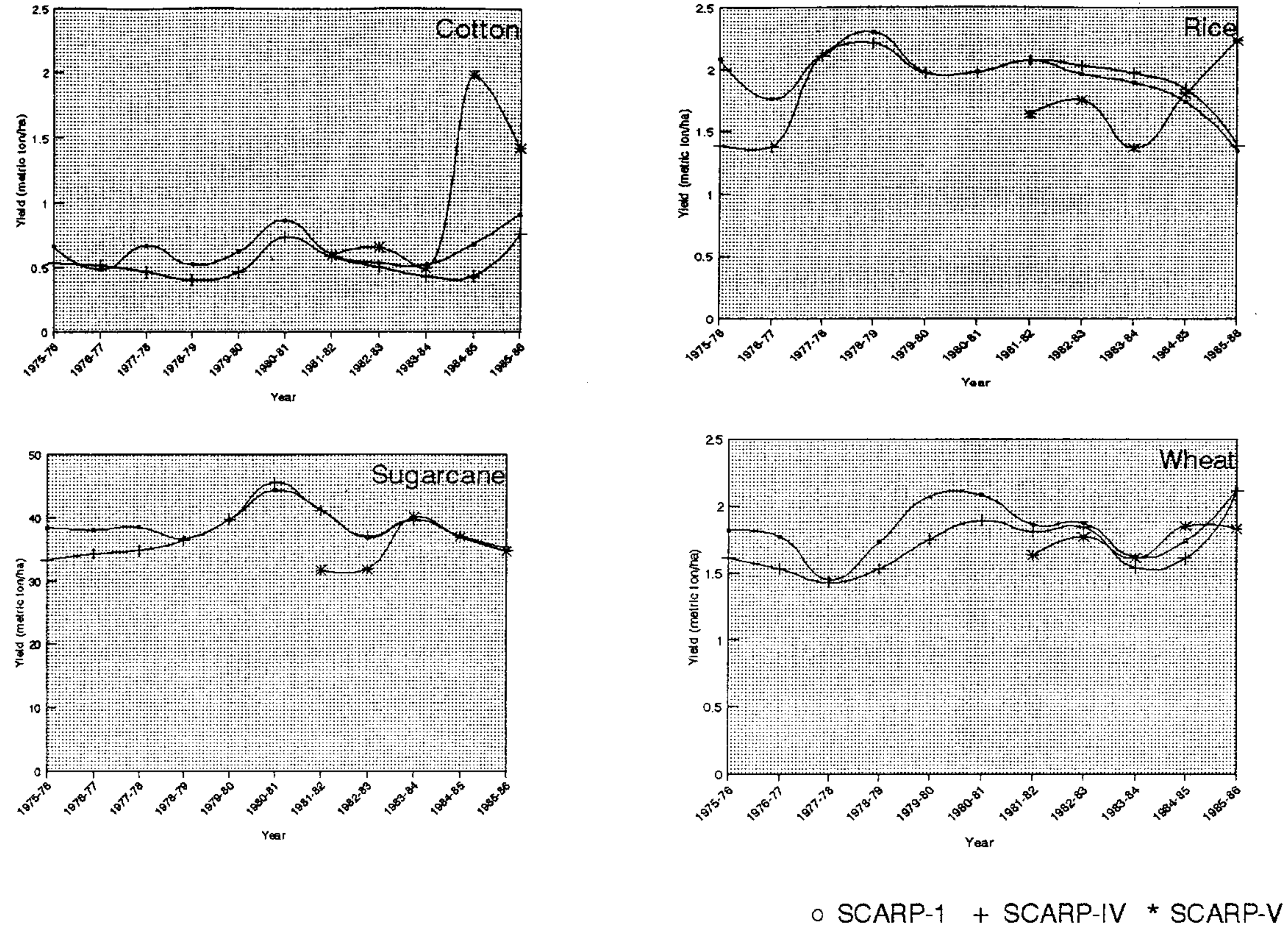


Figure 29 Yield of Crops in SCARP Areas of Rechna Doab, Punjab, Pakistan.

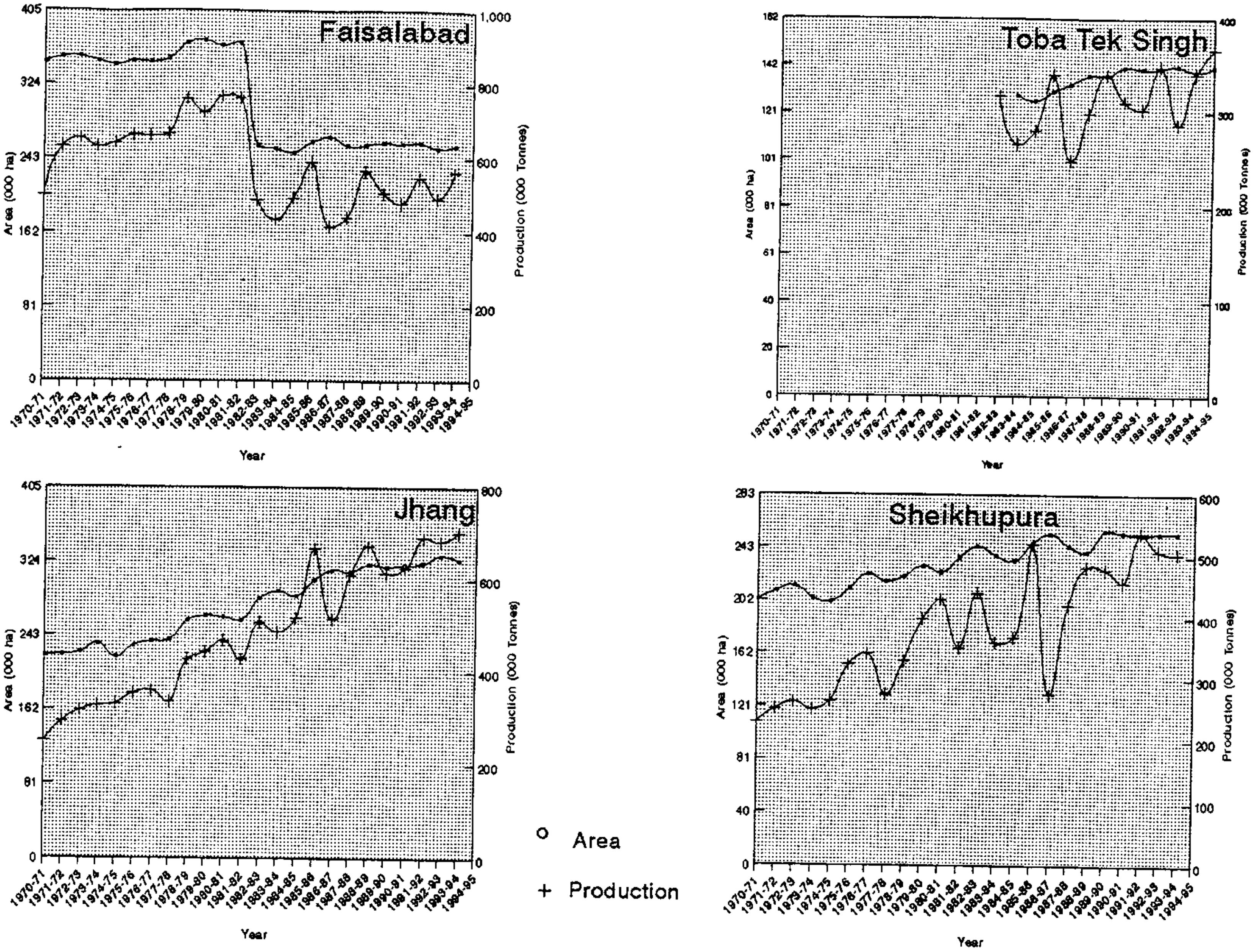


Figure 30 Temporal Comparison of Area and Production of Wheat for Districts overlapping SCARPs I, IV & V, Rechna Doab, Punjab, Pakistan.

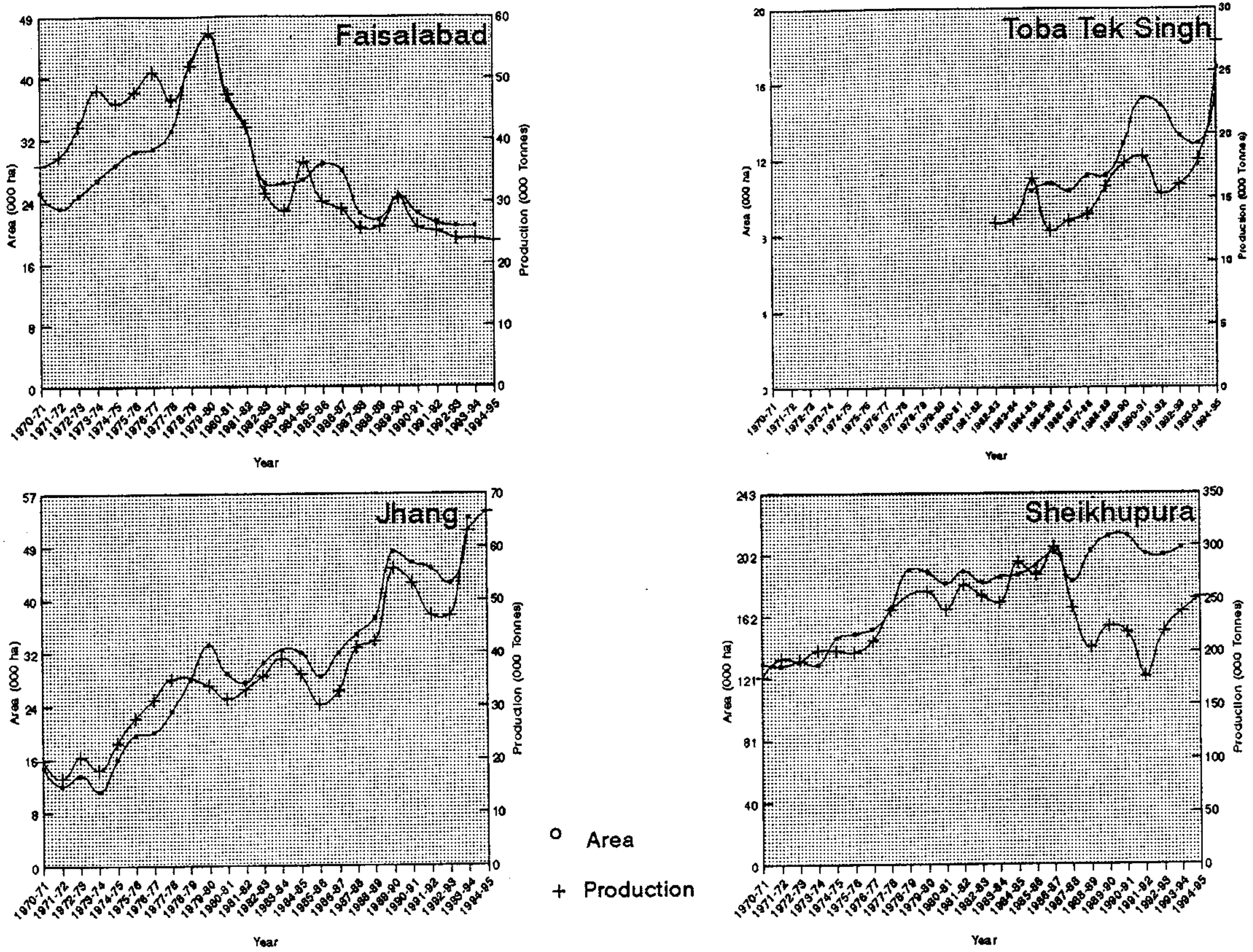


Figure 31 Temporal Comparison of Area and Production of Rice for Districts overlapping SCARPs I, IV & V, Rechna Doab, Punjab, Pakistan.

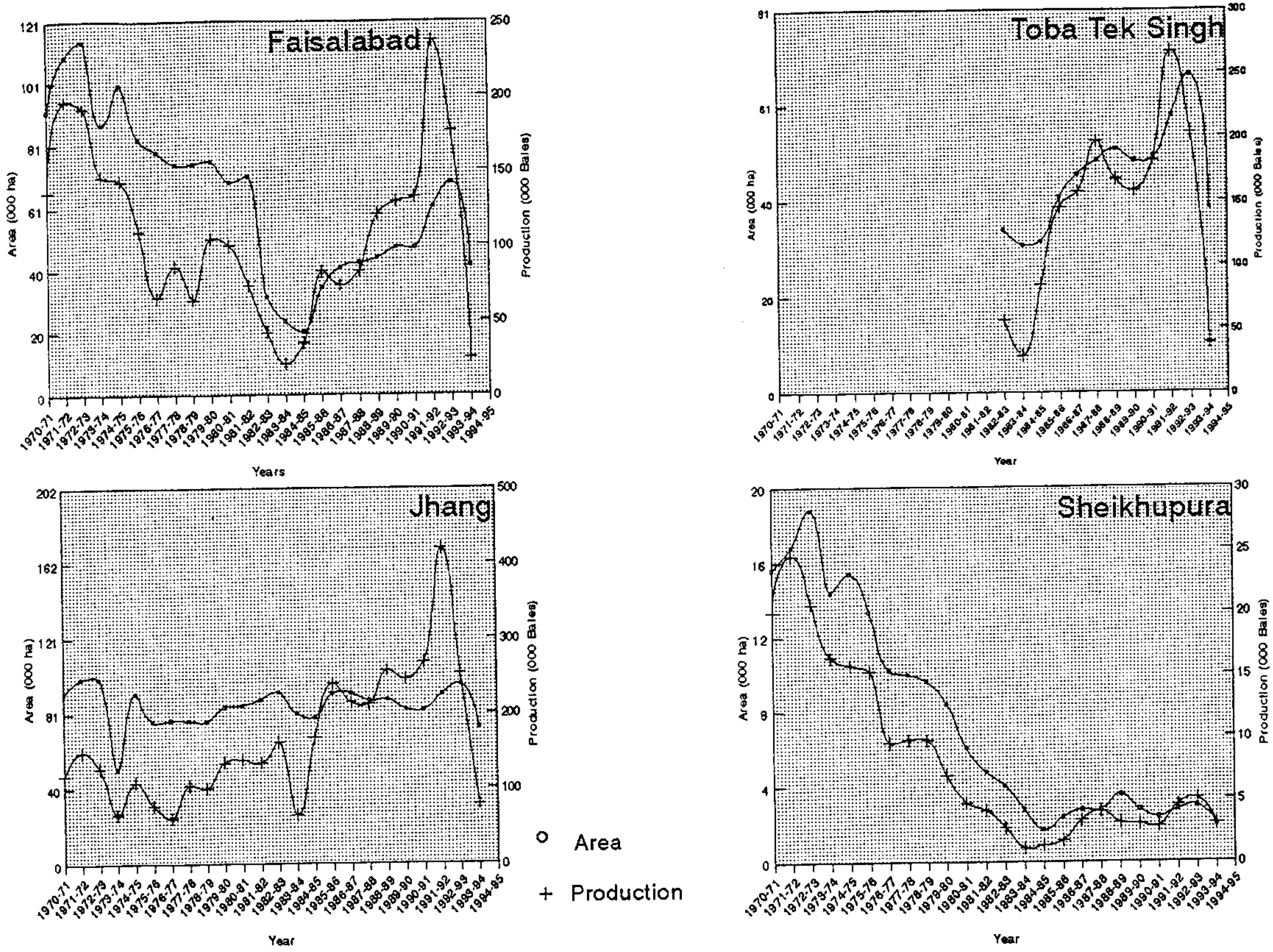


Figure 32 Temporal Comparison of Area and Production of Cotton for Districts overlapping SCARPs I, IV & V, Rechna Doab, Punjab, Pakistan.

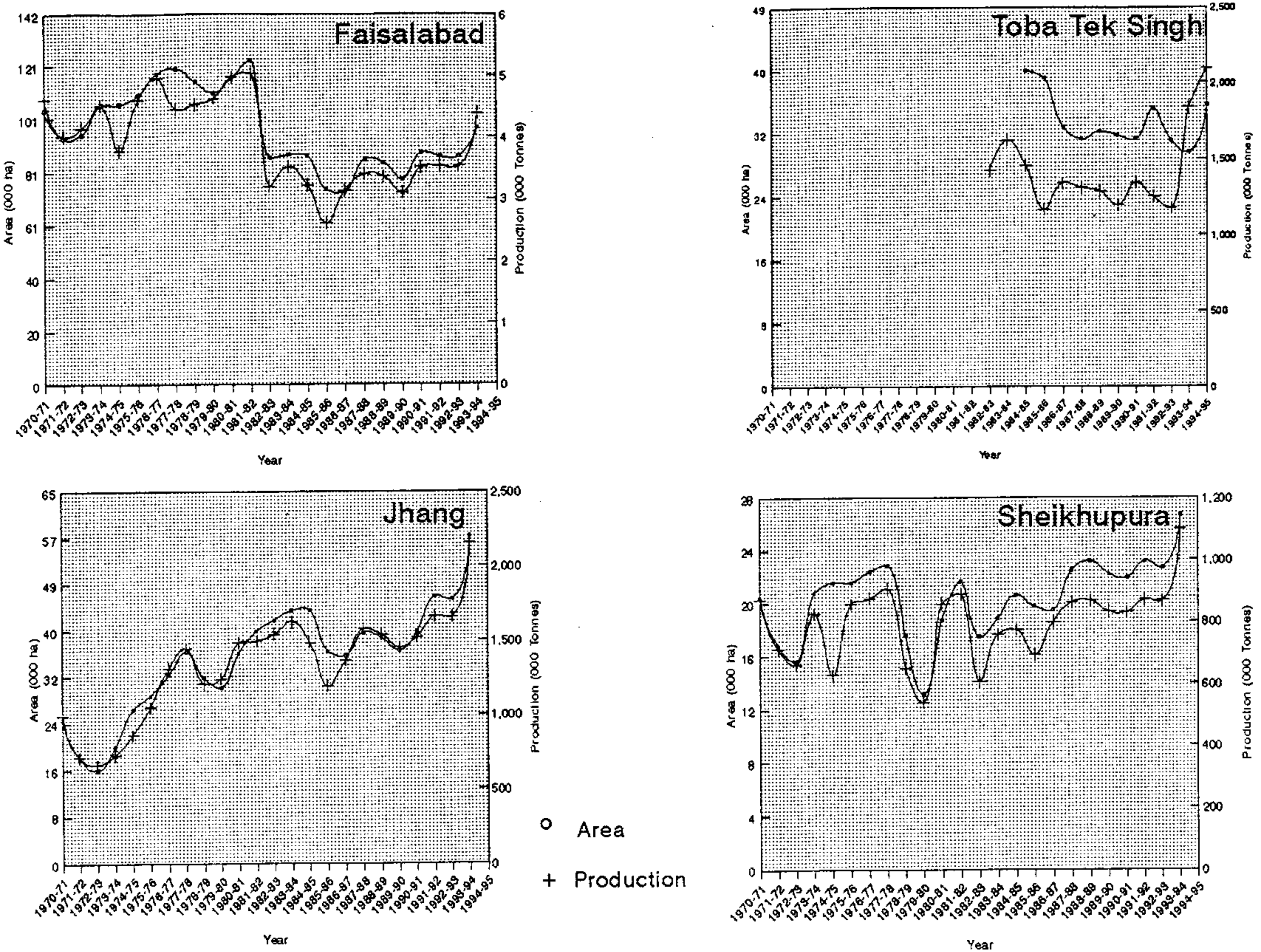


Figure 33 Temporal Comparison of Area and Production of Sugarcane for Districts overlapping SCARPs I, IV & V, Rechna Doab, Punjab, Pakistan.

are slackening despite continued growth in area under its cultivation. In the absence of genuine reasons to link this gap to an increase in salinity or waterlogging, a likely reason may be an over-reactive reliance on private pumpage to compensate for the outstretched system supplies. The magnitude of fluctuations in the statistics for sugarcane have stabilized greatly and appear set for continued upward growth.

The District of Jhang in the south of the Rechna Doab has shown changes in the area and production of wheat that are totally opposite and equivalent in magnitude to the loss in the Faisalabad District. When comparing for higher consumptive use crops, sugarcane production in Jhang has surpassed Sheikhupura due largely to higher cropped land being set aside for this purpose; Sheikhupura, however, has the highest production of rice within the Rechna Doab.

In Toba Tek Singh, somewhat erratic but steeper increases have been observed in production for all of the crops, especially cotton. These increases in a transitional agroclimatic zone, that also includes Jhang District, have been on the upswing in a manner not consistent with a proportional increase in area. This intensification reflects a direct benefit of the improvements in land and watertable conditions effected by SCARP V. If this intensification was borne out by significant increases in yield, then based on Figure 27, where they overtake comparative figures for SCARP-I & IV by 1984-85, the corresponding increases in production at the district level are noticeable for rice and cotton and to a much lesser extent for wheat.

D. Longevity of Wells

The SCARP wells in the Rechna Doab operated in the capacity range between 2-5 cusecs (57-142 lps) (Table 18, page 65). This design discharge could not be sustained due to a decrease in the specific capacities at an average rate of 3 to 7% per year, thereby causing a reduction in pumpage. The behavior of tubewells in saline groundwater zones was even worse; corrosion severely affected the pump impellers and shafts, thus necessitating earlier than expected replacements (Table 19). This does not apply to those saline groundwater tubewells that have a far less utilization rate as compared to the tubewells in FGW areas.

Table 20 provides comparative figures for the decrease in specific capacity for two principal reclamation schemes in the Rechna Doab. Not only is this decrease not uniform but the maximum affectation below 80% of acceptance specific capacity occurs within the first 12 years of operation. Results of analysis to correlate acceptance specific capacity with tubewell pumpage deterioration (SCARPs I & IV) indicates greater longevity for tubewells with a lower value of acceptance (80-100 gpm/ft).

Table 19. Availability of Performance Data (Original Wells) Based on Number of Tubewells.

Schemes	Number of Tubewells After Different Time Period (Years)							
	4	8	12	15	18	20	25	28
SCARP-I								
Total	1669	1595	1386	1257	1067	991	810	560
SCARP-IV								
Muridke	573	572	534	490	402	361	- -- -	
Mangtanwala	309	305	233	181	151	69		
SCARP-V								
Shorkot Kamalia	101	98	89					
Satiana Pilot Project	69	65	50					

Source: Arif (1993)

Table 20. Non-Replaced SCARP Tubewells as Affected by Reduction in Specific Capacity in the Rechna Doab, Punjab, Pakistan.

SCARPs	Specific Change, as % of Acceptance	Years of Operation					
		4	12	18	20	25	28
SCARP-I	100 - 80	1125	335	131	104	62	30
	80 - 60	416	283	217	212	137	61
	60 - 40	158	419	318	297	239	128
	< 40	39	527	428	397	379	345
SCARP-IV	100 - 80	740	164	90	74	-	-
	80 - 60	100	129	90	81	-	-
	60 - 40	34	161	128	106	-	-
	< 40	8	313	245	169	-	-

Table 21. Scheme-wise Decline in Water Tables in the SCARP-I Reclamation Area of Rechna Doab, Punjab, Pakistan.

Scheme	Average decline of the water table in 1960-61 to June 1968, in meters
Harse Sheikh	0.7
Hafizabad and Pindi Bhattian	1.61
Khangah Dogran	2.28
Beranwala	0.91
Sangla	1.65
Shah Kot and Chuharkana	1.65
Shadman and Chichoki Millian	0.67
Zafarwal	2.68
Jaranwala	0.67
Average for SCARP-I	1.43

Source: Mallmberg, 1968

E. Project-wise Achievements

1) SCARP-I

a) Early History

Pumping began in areas comprising SCARP-1 at irregular intervals, starting in 1954 with the four widely scattered schemes completed by the Irrigation Department (see VI (c) above). The planning for SCARP-I comprised eight additional schemes. In 1959, the PID schemes were also officially transferred to WAPDA for operational and adminitrative control (Figure 34). By July 1962, most of the wells had been placed in operation except in Shahkot and Zafarwal schemes where full scale pumping started in October 1962 and March 1963, respectively. With the exception of the Jaranwala Scheme, the schemes were small and the lowering of the watertable in response to pumping was highly localized.

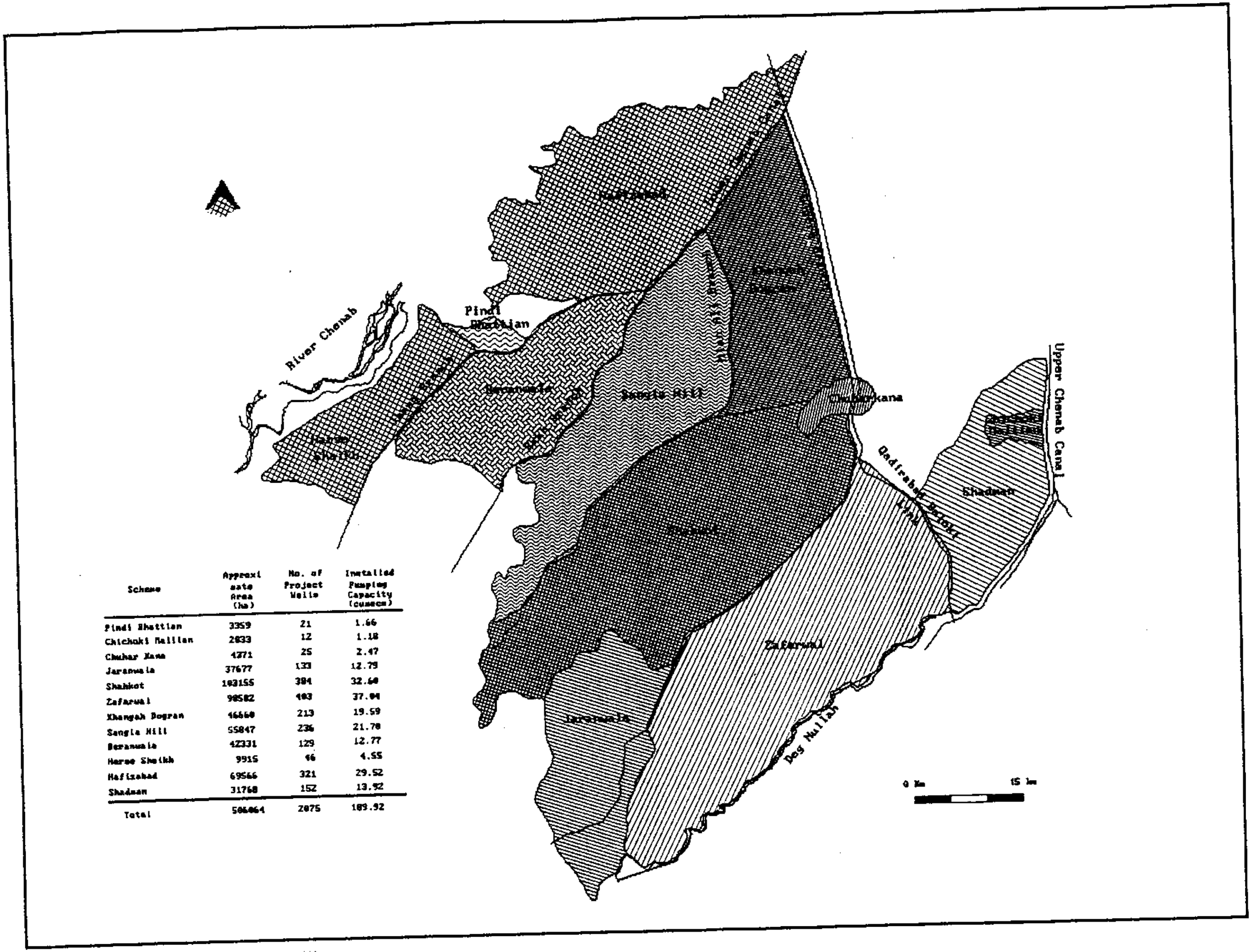
Prior to the begining of groundwater reclamation in 1960-61, the watertable was above the land surface in approximately 4,000 ha of SCARP-1 (WAPDA, 1959). The inundated areas were largerly in the northeastern part of the project in areas adjacent to the Upper Gugera Branch and Lower Chenab canals. Ponding, from a few inches to a foot, occured in about 728 ha in Khanqah Dogran Scheme, 688 ha in Harse Sheikh, and 648 ha each in the Shahkot, Sangla, and Zafarwal schemes. The total quantity of water in these ponds probably never exceeded 600 hm, a volume of insignificant effect on the hydrologic budget.

b) Groundwater Quality

In SCARP-I, where there is little direct return flow to the rivers and only a small amount of groundwater underflow to adjacent areas, pumping from wells was likely to create a closed circulation system that gradually results in increased concentration of total dissolved solids (TDS). Swarzenski (1968) has shown that for groundwater in the Rechna Doab having TDS < 300 mg/l, the dominant ions in solution are Ca, Mg, and HCO3; for the TDS range 500-1000, its Na, HCO3, or a mixture of HCO3, Cl and SO4. The dominant ions in TDS concentrations exceeding 3000 mg/l are Na and Cl. Against the redissolution of the more soluble salts of Cl and SO4 in the soils through irrigation, an increase in the concentration of chloride and sulfate in the groundwater may be an indication that percolation of irrigation water has moved vertically to the depth of the well screen.

Groundwater in the northeastern two-thirds of SCARP-I has an SAR value of < 10, whereas to the southwest, notably in Beranwala, Shahkot, Jaranwala, and Sangla schemes it exceeds 10. For small areas in Shahkot, Zafarwal, and Sangla schemes, the SAR exceeds 18 which constitutes a serious sodium hazard.

While reasons for the relatively higher concentrations of the dissolved solids in the Shahkot, Zafarwal, and Jaranwala schemes of SCARP-I are not known, it seems highly probable that their existence is due to the impedance of groundwater circulation by the underlying bedrock



Scheme	Approximate Area (ha)	No. of Project Wells	Installed Pumping Capacity (cumecs)
Pindi Bhattian	3359	21	1.66
Chichoki Mallian	2833	12	1.18
Chuhar Kana	4371	25	2.47
Jaranwala	37677	133	12.79
Shahkot	103155	384	32.60
Zafarwal	90582	403	37.04
Khangah Dogran	46660	213	19.59
Sangla Hill	55847	236	21.70
Beranwala	42331	129	12.77
Haree Sheikh	9915	46	4.55
Hafizabad	69566	321	29.52
Shadman	31760	152	13.92
Total	506064	2075	189.92

Figure 34 Salinity Control and Reclamation Project, SCARP-I, Punjab, Pakistan.

of the Shahpur-Delhi buried ridge that extends eastward from Chiniot to Sangla and then southeast from Shahkot to Mangtanwala. Kung (1990) has described preferential flow paths in the sandy vadose zones as the mechanism through which groundwater contamination can take place over a short period of time. Since these flow paths recharge the watertable at distinct points, the dispersive nature of these point sources should lead to a wider scatter of quality over short distances.

c) Mid-term Investigations

Investigations made by the USGS (Malmberg, 1968) in the SCARP-I indicated that pumping had more than doubled the irrigation supply and lowered the watertable to a depth of more than 3 m across much of the project area. As a result, more than 66% of the 162,000 ha of land damaged by waterlogging and salinity was wholly or partially reclaimed. The cropping intensity was increased from about 77% in 1962 to 101% in 1968.

Figures 35-37 indicate the temporal variations in pumpage across SCARP-I schemes for the two growing seasons. The schemes occupying the center of the project area (Shahkot, Harse Shaikh, Sangla Hill, Khanqah Dogran, and Beranwala) have experienced a steady decline in pumpage across both seasons. The abstractions during Kharif have been higher than Rabi most of the time. Since the installed pumpage capacity (as well as the number of tubewells) of these schemes was 48% of the total and across more than 50% of the project area, these reductions (more than 50% of the original by mid-1980s) have significant implications towards estimation of the groundwater balance within the area. Just how much pumpage is available from this area 10 years thence requires close scrutiny of the SMO records.

What schemes like Pindi Bhattian, Chichoki Mallian, and Chuharkana have in common is their small size (2% of the total), fewer tubewells (2.8%), and installed capacity (also 2.8%). They also have one other thing in common; their Rabi contributions have showed periods of great stability, especially in Chuharkana, that have picked up towards the end of the review (1985-86). The fluctuations in pumpage for both Kharif and Rabi, as observed over a 21 year period, are unlike the steady trend in deterioration for the schemes in the center of the project area. One logical explanation could be the geographical proximity of these schemes to zones of recharge like the Upper Chenab Canal, Upper Gugera/QB Link, and Chenab River that sustain subterranean inflows to the pump sites on a permanent basis. Also, pumpage close to these FGW zones was less likely to corrode the impellers as compared with the tubewells in SGW zones.

For tubewells in Shadman, Zafarwal, Jaranwala, and Hafizabad schemes, the early reductions in pumpage, in some instances upto 50%, have been followed by a reversal that recuperated upto half of the reduction in pumpage suffered since pumping began. All of these schemes had experienced drastic reductions in Rabi pumpage during early years of operation, followed by periods of steady decline until about the 11th or 12th year of operation that saw the upward swing.

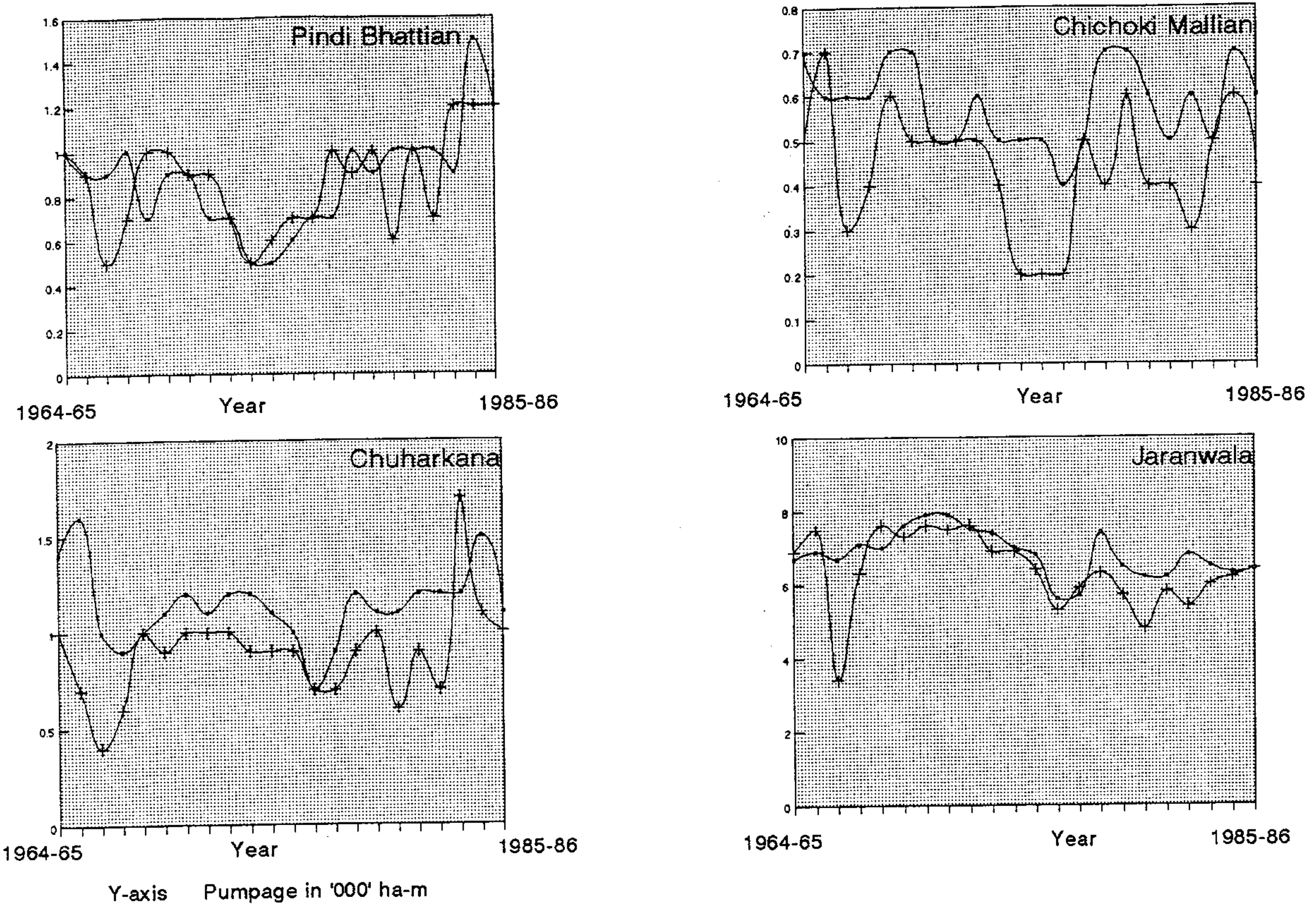


Figure 35 SCARP-I Tubewell Pumpage in Pindi Bhattian, Chichoki Mallian, Chuharkana, Jaranwala, Rechna Doab, Punjab, Pakistan.

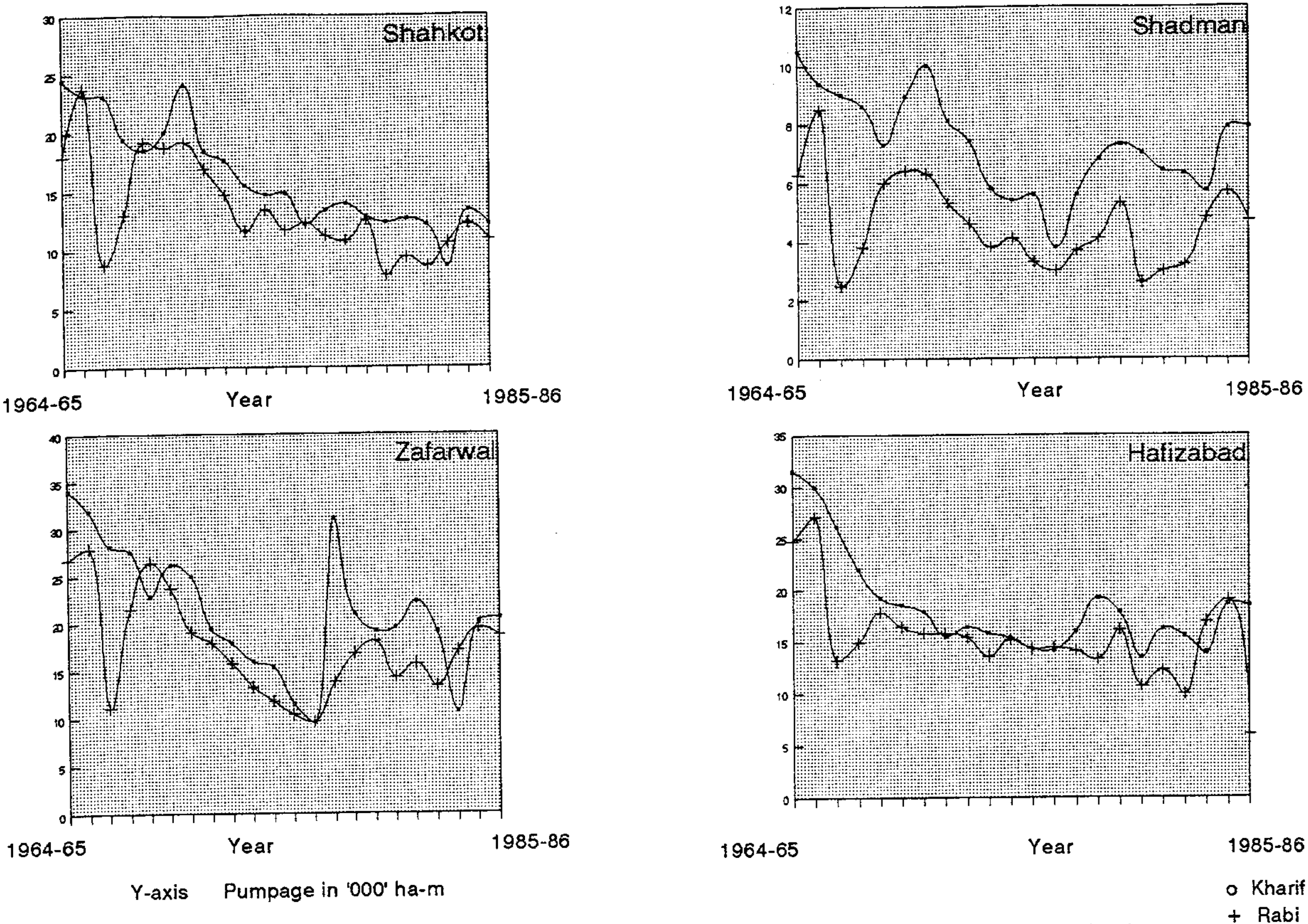


Figure 36 SCARP-I Tubewell Pumpage in Shahkot, Shadman, Zafarwal and Hafizabad, Rechna Doab, Punjab, Pakistan.

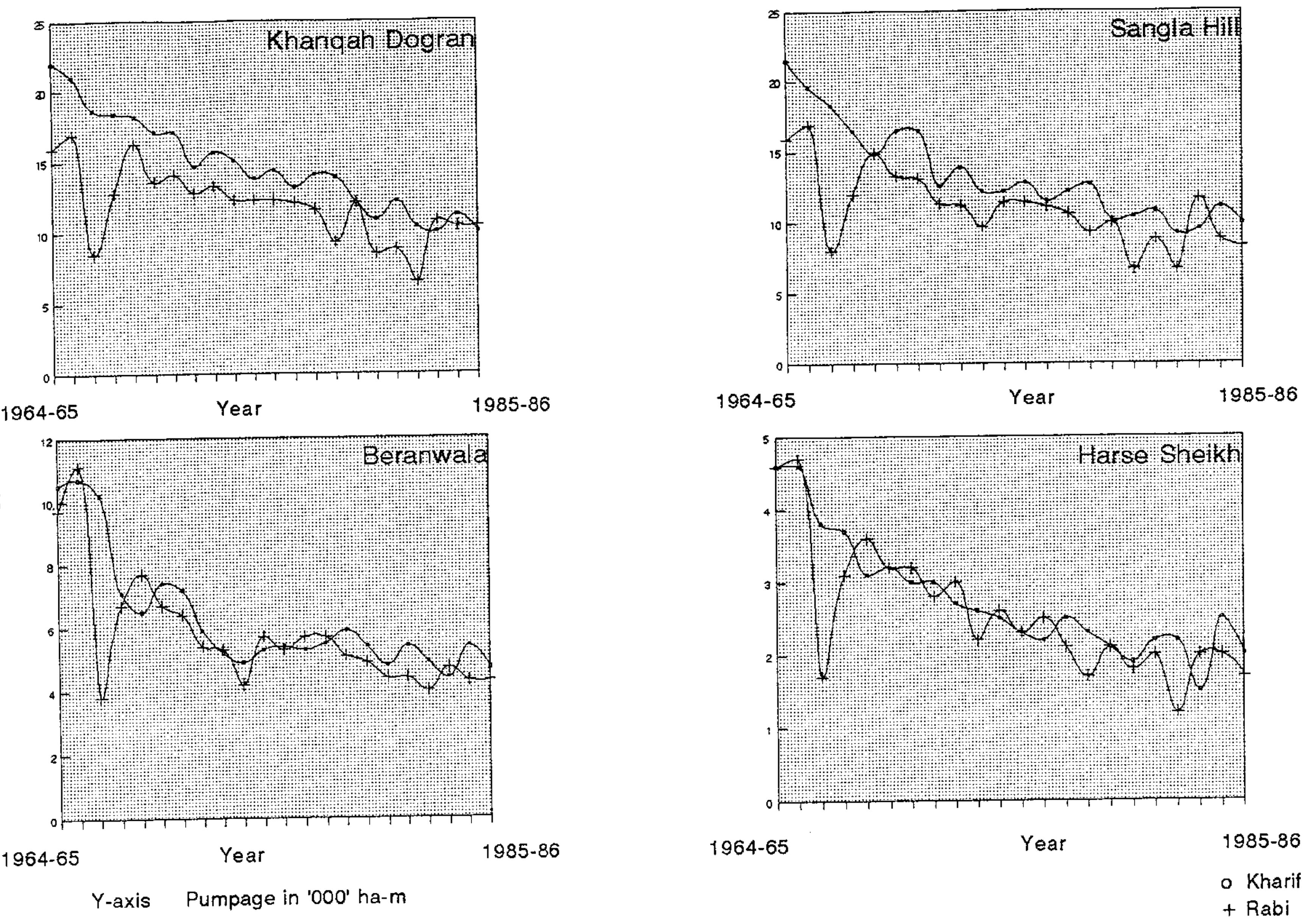


Figure 37 SCARP-I Tubewell Pumpage in Khanqah Dogran, Sangla Hil, Beranwala and Harse Sheikh, Rechna Doab, Punjab, Pakistan.

Data analysis upto 1968 indicates that for an annual average of about 284,000 hm of pumping in the SCARP-I since start of operations, the lowering of the watertable has been scheme-specific; maximum being for the Zafarwal and minimum for the Jaranwala and Shadman. The lowering has been unrelated to the gross pumpage occurring in the individual schemes based on tubewell capacity and density (Table 21, page 82).

By June 1968, in response to a net depletion of 0.2 Mhm from the reservoir (despite a net recharge of 1.267 Mhm), three distinct cones of depression, separated by seepage divides, had developed in Zafarwal, Khanqah Dogran, and Hafizabad schemes towards locale-specific lowering of the watertables (Figure 38).

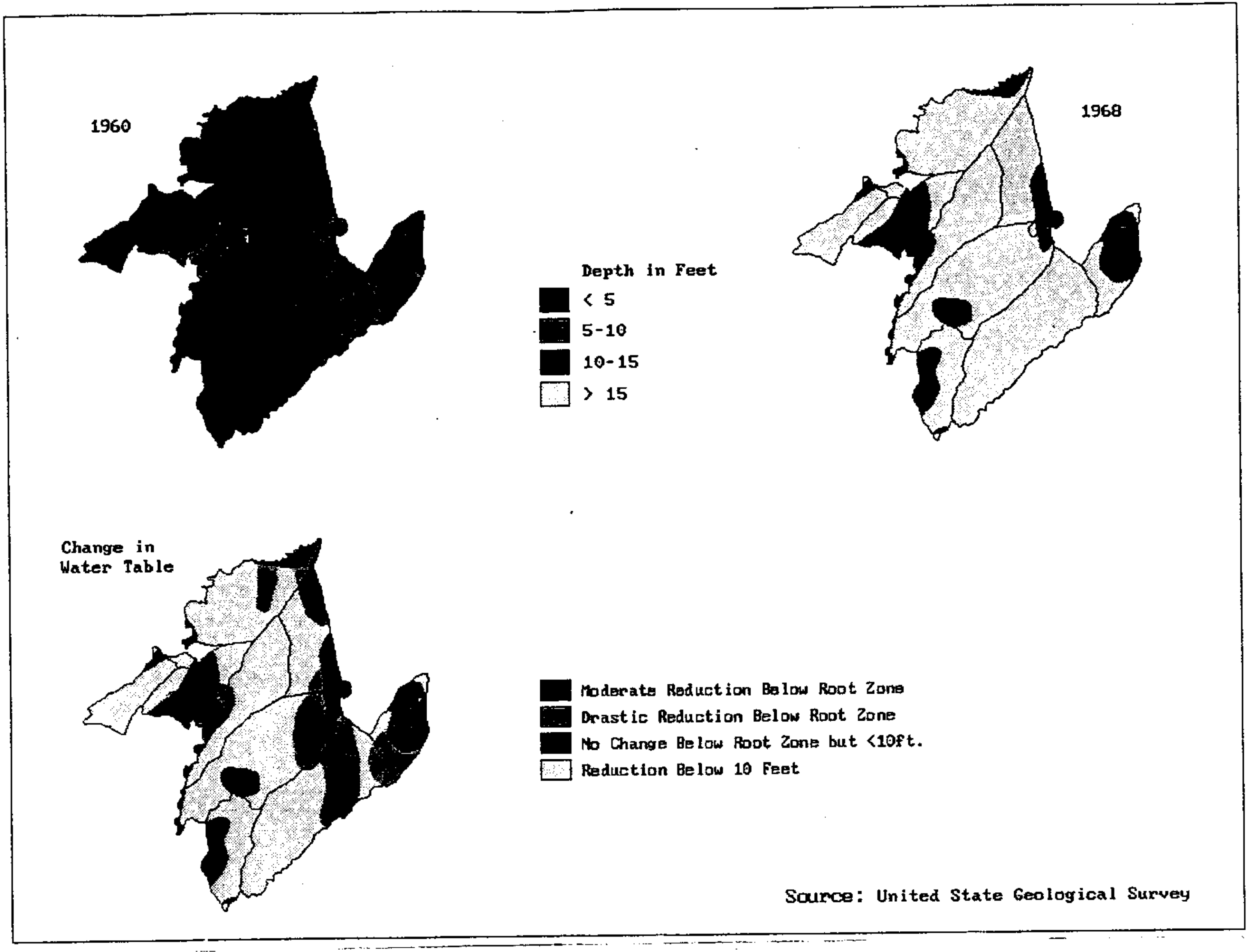
The drains in the SCARP-I, like elsewhere in the Rechna Doab, convey effluent groundwater seepage as well as precipitation runoff to the bordering rivers. By May of 1965, the watertable had been lowered below the bed of most of the Deg Nala and Jaranwala drainage network. Remaining flows thus mostly correspond to the storm water runoffs, whereas the estimated 10,500 hm of groundwater seepage flowing through these drains has been consumed by public and private tubewells. However, this did not happen in the catchment of the Chiniot and Ahmedpur Kot Nikka drainage network where flows continued to be derived from groundwater seepage.

d) Performance Assessment

As an operational test case, SCARP-I is quite representative of WAPDA's efforts to combat waterlogging and salinity in the Rechna Doab area. In 1961, the watertable in 75% of the project area was within 3 m of the surface; in 1971 it declined by 2.6 m and in only 8.1% of the area was the watertable less than 3 m deep. However, subsequent well deterioration as well as abnormal rainfalls and floods resulted a rise in the watertable. In 1977, about 33% of the project area had less than 3 m depth to watertable with an average depth of 3.8 m against a pre-project value of 2.6 m. An area of 138,000 ha out of a total affected area of 172,125 ha had been reclaimed. Similarly, salinity had shown considerable improvement in the project to the extent of 22% as compared with 1961 survey (Rathur, 1982).

In 1970 SCARP-I was declared completed and handed to the Punjab Irrigation and Power Department for maintenance. By then, nearly 0.5 Mha were being utilized for winter and summer crops versus a target figure of 0.55 Mha. A comparison of the aerial photographs taken twenty-three years apart (1953-54 vs 1976) shows:

- A few salinized tracts were brought under cultivation, which occurred generally on the margins of saline land, and where the salinity occurred as small patches in a complex pattern;



Source: United State Geological Survey

Figure 38 Temporal Changes in Depth to Watertable (1960-68), SCARP-I, Punjab, Pakistan.

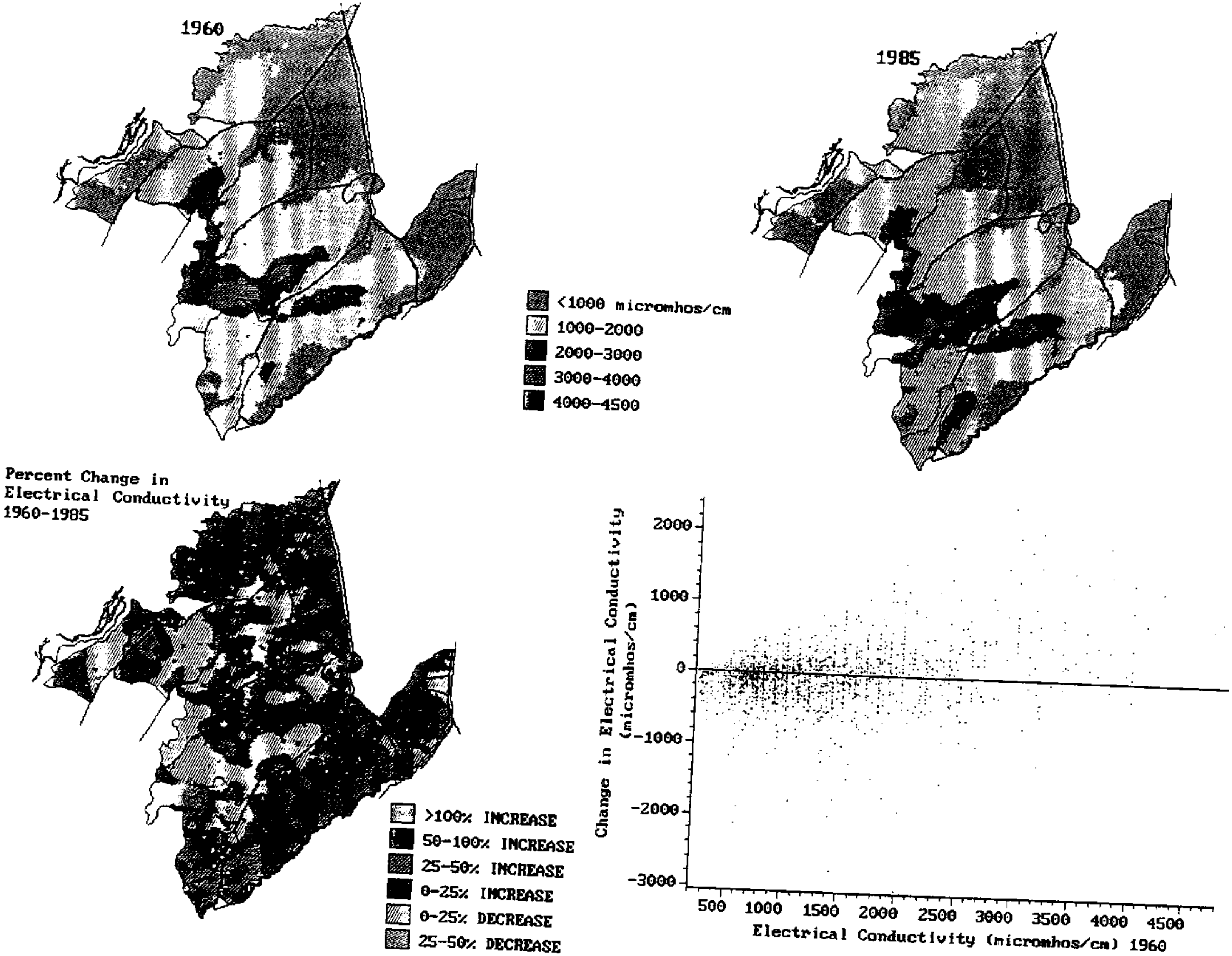
- Surface waterlogged areas either disappeared altogether or were reduced in extent;
- Large tracts of salt-affected lands remained out of cultivation.

To qualitatively assess the changes in groundwater quality brought about by long term pumpage, the electrical conductivities of SCARP-I tubewell pumpage have been compared across 25 years of time. From Figure 39, it can be concluded that:

- the low values of EC in either time periods are concentrated along zones of high recharge, i.e. large irrigation canals;
- the 1000-2000 micromhos/cm regime has encroached on the lower values of EC, especially in the Chuharkana, Shadman, and Zafarwal schemes;
- pockets of salinity in the Zafarwal scheme have degraded further;
- smaller schemes like Pindi Bhattian, Chuharkana, and Chichoki Mallian have experienced little or no change in the specified salinity ranges;
- areas in the immediate vicinity of the Chenab River have been minimaly affected;
- majority of the pumpage regime has experienced upto a 25% increase in electrical conductivity with respect to 1960 benchmark levels;
- higher percentage increases in salinity have a large spatial scattering, but area mostly restricted to Shahkot, Jaranwala, and Zafarwal schemes;
- improvements have occurred, rather surprisingly, across the saline belt of Shahkot, Sangla Hill, and Beranwala schemes;
- the fresh water regime in the head reach of the system near Hafizabad has suffered drastic increases in EC values, but still remain under the 1000 micromhos/cm limit; and
- reductions in the quality of water have been more pronounced in the lower EC ranges, whereas the converse is true for highly saline waters.

Figure 40 presents the temporal spate of changes in the quality of SCARP-I tubewell waters at five year intervals. The criteria has been as follows;

Fresh/Slightly Saline-----------EC < 1500 micromhos, SAR < 6
Moderately Saline Sodic------EC 1500-3000, SAR 6-10
Strongly Saline------------------EC > 3000, SAR < 6
Strongly Saline Sodic-----------EC > 3000, SAR > 10



Source: Soil Monitoring Organization, WAPDA

Figure 39 **Temporal Comparison of Changes in Electrical Conductivity in SCARP-I, Rechna Doab, Punjab, Pakistan.**

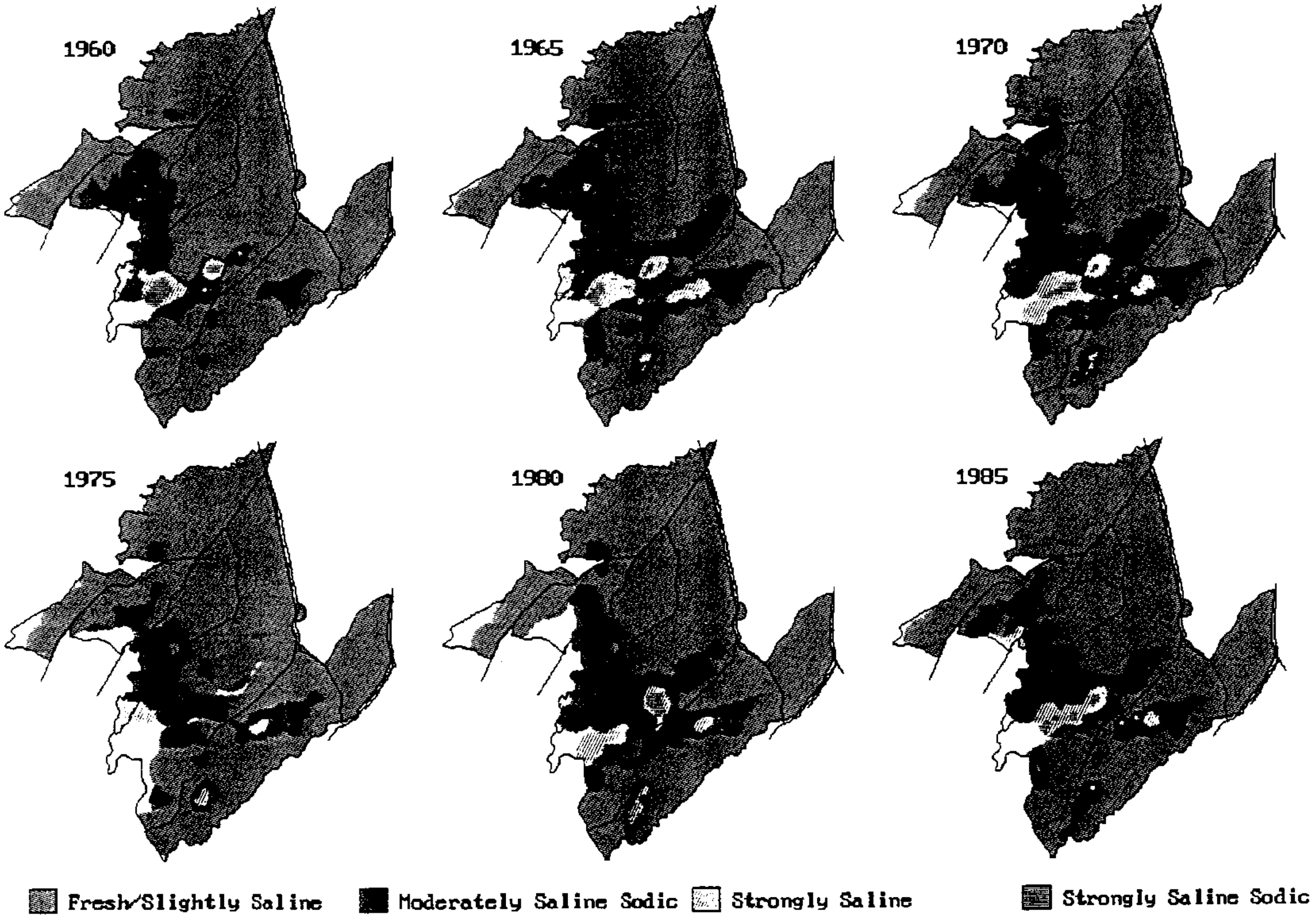


Figure 40 Comparison of Water Quality at Selected Time Intervals for SCARP-I, Rechna Doab, Punjab, Pakistan.

The moderately saline sodic waters increased very significantly during the early years of pumpage before ebbing to the in lowest in the mid 1970s, followed by a moderate but stable increase towards the end of the comparison period. The saline/saline sodic pockets advanced from localized regime near Shahkot to areas on either side of the Lower Gugera channel. By 1985, these highly saline sodic waters had receded back to areas eastwards of Shahkot. In of all these years, the most noticeable and unrelenting affectation has been in the Zafarwal scheme where highly saline pockets have assumed a permanence across extensions of moderately saline-sodic conditions.

The latest figures on qualitative improvements to land are provided in Table 22, which on comparison with the previously shown overall situation for the Rechna Doab (Figure 25), indicates that even though pre-project salinity affectation was higher in SCARP-I, the status of non-saline land had surpassed the doab average assessed by the 1977-78 WAPDA MPR survey. From the same table, the much lower percentage of "disaster" area under depth to watertable seems to augur well for the control strategy adopted by WAPDA, other considerations aside. In fact, WAPDA's overemphasis on reduced water levels below 3 m depth stemmed from the permissible depth to watertable requirements of major crops in the area (Table 23). Since supplies from the FGW zones were also increasing the cropping intensities of these crops (Table 24), maintenance of an adequate salt balance in the root zone, and concommitant threshold limits on tolerance, also figured in the overall enhancement of supplies. Subsequent research by Ahmad (1988) on crop salt tolerance within Punjab has established the functional relationship for yield decrement at a particular salinity level. The threshold limits so identified are given in Table 25.

2) Mangtanwala and Muridke (SCARP-IV)

The feasibility report of SCARP-IV was submitted in June 1965 covering the entire Upper Rechna area. On the basis of a barter protocol between the GoP and the then Yugoslavia, M/s Geotechnika and M/s Energoinvests submitted proposals for construction of Marrala-Ravi Link unit of SCARP-IV for tubewell construction and electrification, respectively. The signed contracts could not be initiated in earnest due to the Indo-Pak war, and subsequently the contract work was transferred from the M-R unit to the Mangtanwala unit. The awarded contract covered construction of 300 tubewells, later revised to 311, having a total designed capacity of over 35 cumecs.

During the construction of the Mangtanwala unit, the same contractors were invited to submit additional proposals for construction of the Muridke unit northwards of Mangtanwala. The proposals, submitted in June 1967, orginally envisaged construction of 580 tubewells with a total discharege capacity of nearly 62 cumecs; the number of wells was later revised to 624 for a total of 935 tubewells as part of the SCARP-IV project. The total area of the Mangtanwala/Muridke units is 2,25,652 ha.

Table 22. Effect on Drained Land Quality of SCARP-I in Rechna Doab, Punjab, Pakistan.

Project	Area with DTW < 1.524 m		Area Free from Surface Salinity		Profile Free from Salinity and Sodicity
	Year	%age	Year	%age	%age
Pre-project	1961	13.5	1953-65	64	34
Post-project	1990	0.3	1977-78	86	70

Source: SMO

Table 23. Effective Rooting Depth and Permissible Depth to Watertable for Major Crops (meters).

Crop	Effective Rooting Depth	Permissible Depth to Watertable
Wheat	1.0 - 1.5	1.0
Maize	1.0 - 1.7	1.1
Cotton	1.0 - 1.7	2.1
Sugarcane	1.2 - 2.0	1.0/1.8

Table 24. Effect on Drained Land Agriculture of SCARP-I in Rechna Doab, Punjab, Pakistan.

Project	Year	Cropping Intensity %age	Yields (tons/ha)				
			Wheat	Rice	Cotton	Sugarcane	Maize
Pre-project	1959-60	80	1.1	1.4	0.5	30	1.1
Post-project	1987-88	115	1.8	1.9	1.1	39	1.3

Source: SMO, WAPDA

Table 25. Tolerance of Agricultural Crops to Soil Salinity in Pakistan.

Crops	Electrical Conductivity of Saturated Soil Extract (dS/m)			
	Threshold	At which yield decreased by		
		10%	25%	50%
Wheat	5.0	5.9	7.2	9.9
Cotton	5.9	8.7	12.7	17.1
Sugarcane	1.8	3.0	5.5	9.8
Rice	4.0	4.6	5.8	7.4

Source: Ahmad, 1990

Table 26. Existing Saline Effluent Disposal from SCARP-V, Rechna Doab, Punjab, Pakistan.

Project	Planned Pumpage (ha-m)	Effluent Quality (ppm)	Destination (ppm)		Salts (Mt)
			Canal	Drain/River	
Satiana	7398.00	3,000	16,000	44,000	0.24
Khairwala Unit	6584.22	2,500		53,400	0.18
Gojra Khewra Phase-I	3205.80	2,368		26,000	0.08
Faisalabad City Drain	2835.90	3,000		23,000	0.09
TSMB Link Project	14796.0	2,760	39,000	81,000	0.45
Gojra Khewra Phase-II	4648.41	2,368		37,700	0.12
Drainage-IV	9247.50	2,350		75,000	0.24
Shorkot Kamalia Saline	11873.79	4,600		96,300	0.60

Source: Main Report; Vol:I Drainage Sector Environmental Assessment National Drainage Program June 1993

The distribution of tubewells by design capacity is listed in Table 18 (page 65). Over 37% of the tubewells in the Muridke unit are of lower capacity (57 & 85 lps) in comparison to the earlier installations of less than 22% in the Mangtanwala unit, where the emphasis was more on the high capacity wells. Interestingly, there were no tubewells discharging at 1/2 cusec (14 lps) incremental intervals in either of the two schemes which was one-third the preference under SCARP-I.

Based on the data, for the number of operational wells remaining after successive time intervals, the fiber glass tubewells of SCARP-IV seemed to outlast the mild steel versions under SCARP-I, especially during the early years of operation (Figure 41). From amongst the various factors responsible for this difference in well deterioration is the design discharge capacity and the quality of water being pumped. SCARP-I had over 47% of the tubewells operating under 3 cusec (85 lps) capacity in comparison to the nearly 32% for SCARP-IV (higher capacity wells are known to suffer from greater loss in specific capacity over time; Memon, 1993).

The earliest data on water quality within SCARP-IV indicates the regime to be fresh to slighly saline. The quality improves with proximity to the Ravi River (Figure 42). An increase in salinity is observed by 1975 principally in those areas that were previously slightly saline. This coincides with a trend that is largely fluctuating between slighltly saline and saline groundwaters for the period between 1970-85; however; this is more prominent in the Muridke unit where the density of tubewells and the concommitant abstractions are also higher. Towards the end of the comparison period, there were indications that that fresh vs saline groundwater divide had migrated closer to the Ravi River. Given the fact that by 1985 a little over 70% of the original tubewells had remained in operation, of which nearly 60% were operating below the 80% acceptance specific capacity, there is reason to believe that much of the pumpage in this area has been assumed by private wells that had historically capitalized on the subterranean seepages from the river. Now, the resultant drawdowns in water levels have reversed the natural flow net in favor of the salinity regime further west. This has not changed the predictability of the dissolved solids either with respect to electrical conductivity (Figure 43), or the Na ionic concentrations (Figure 44).

3) Upper Rechna Remaining (URR)

Upper Rechna's gross area of nearly 470,000 ha is served by three canal systems, all of which derive their supplies from the Chenab River. Only UCC has 156,000 ha out of its 339,000 ha CCA under perennial supplies; neither M-R Link (45,000 ha CCA) or the LCC (52,000 ha CCA) have perennial supplies available for the nearly 110,000 ha of gross area under their commands.

Data on historic canal diversions (0.168 Mhm within the project area out of a total diversion of 1.9 Mhm, 1966-75 average) indicates that, except for the months of May and June, the remaining part of the year is experiencing a deficit of surface water supplies. The shortage

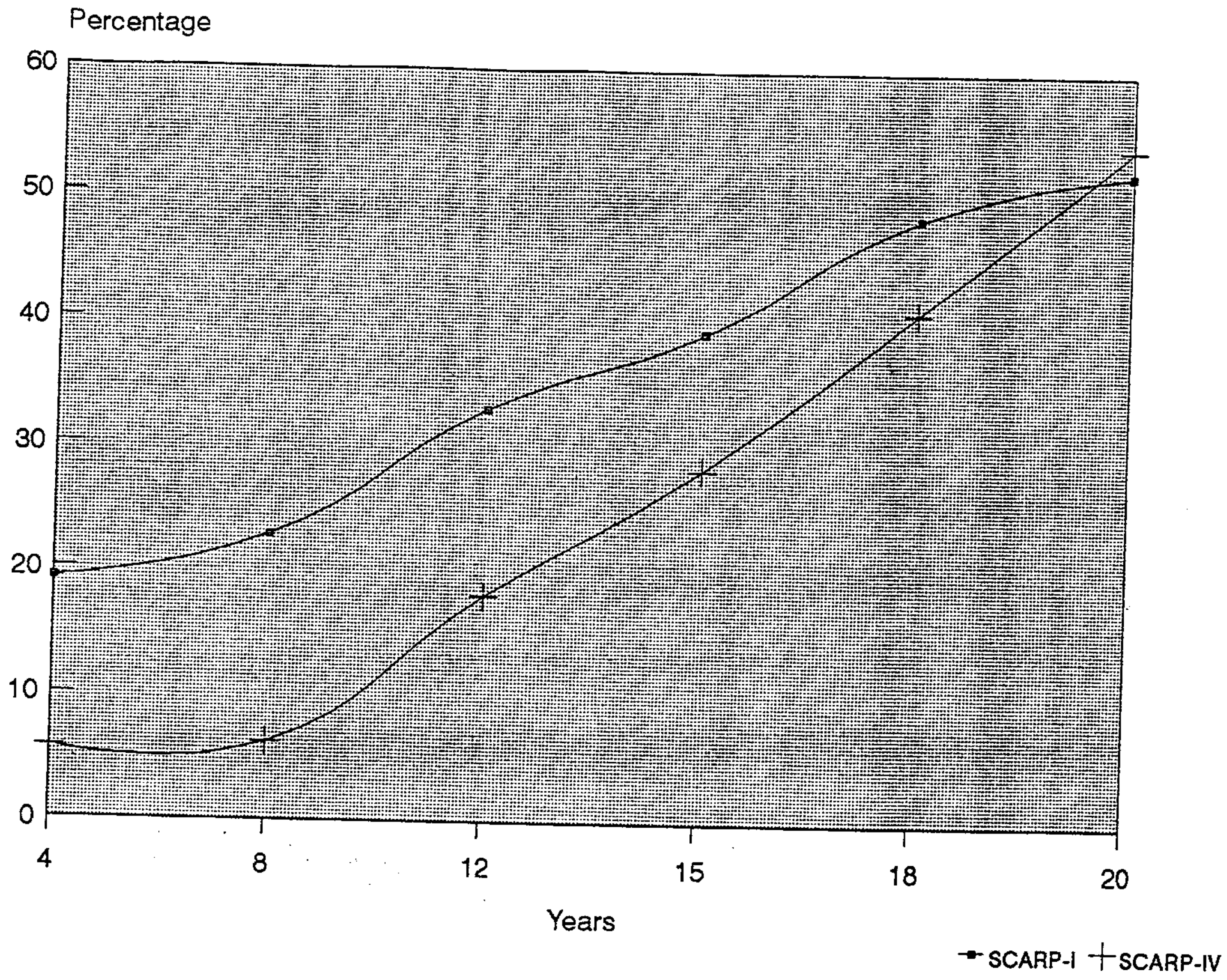
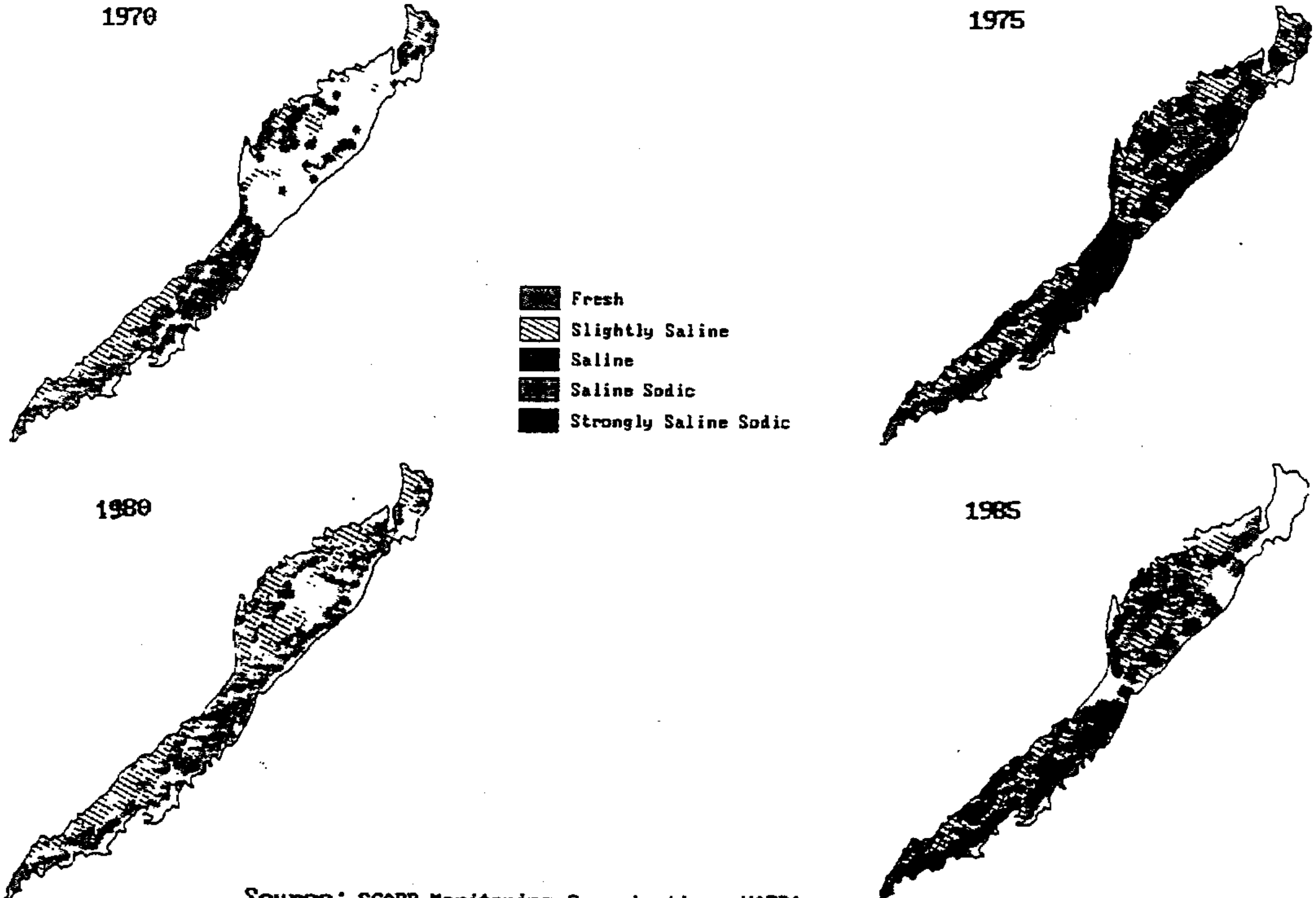
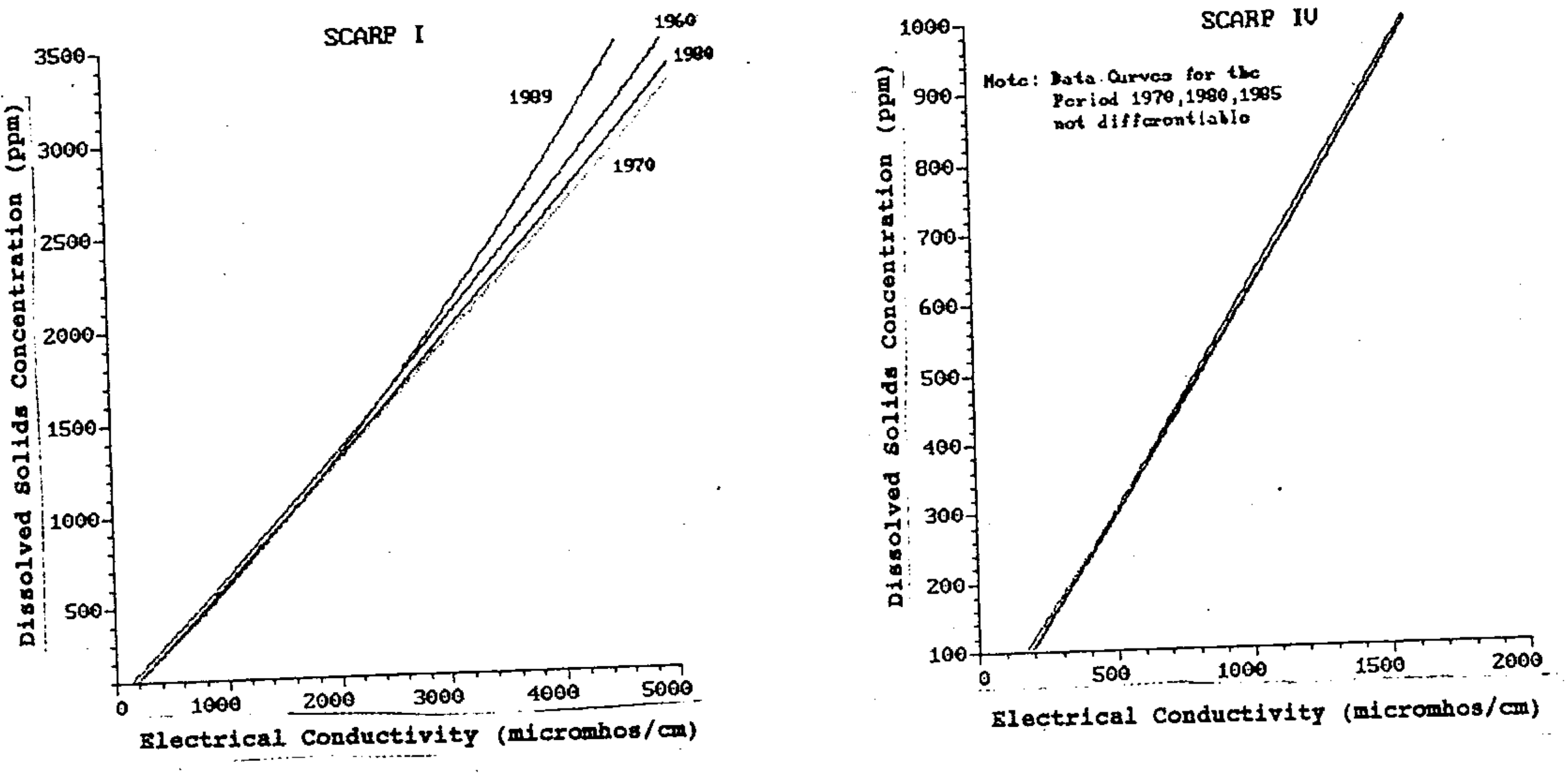


Figure 41 Percentage of Tubewell Replacements/Closure in Selected SCARPs of Rechna Doab, Punjab, Pakistan.



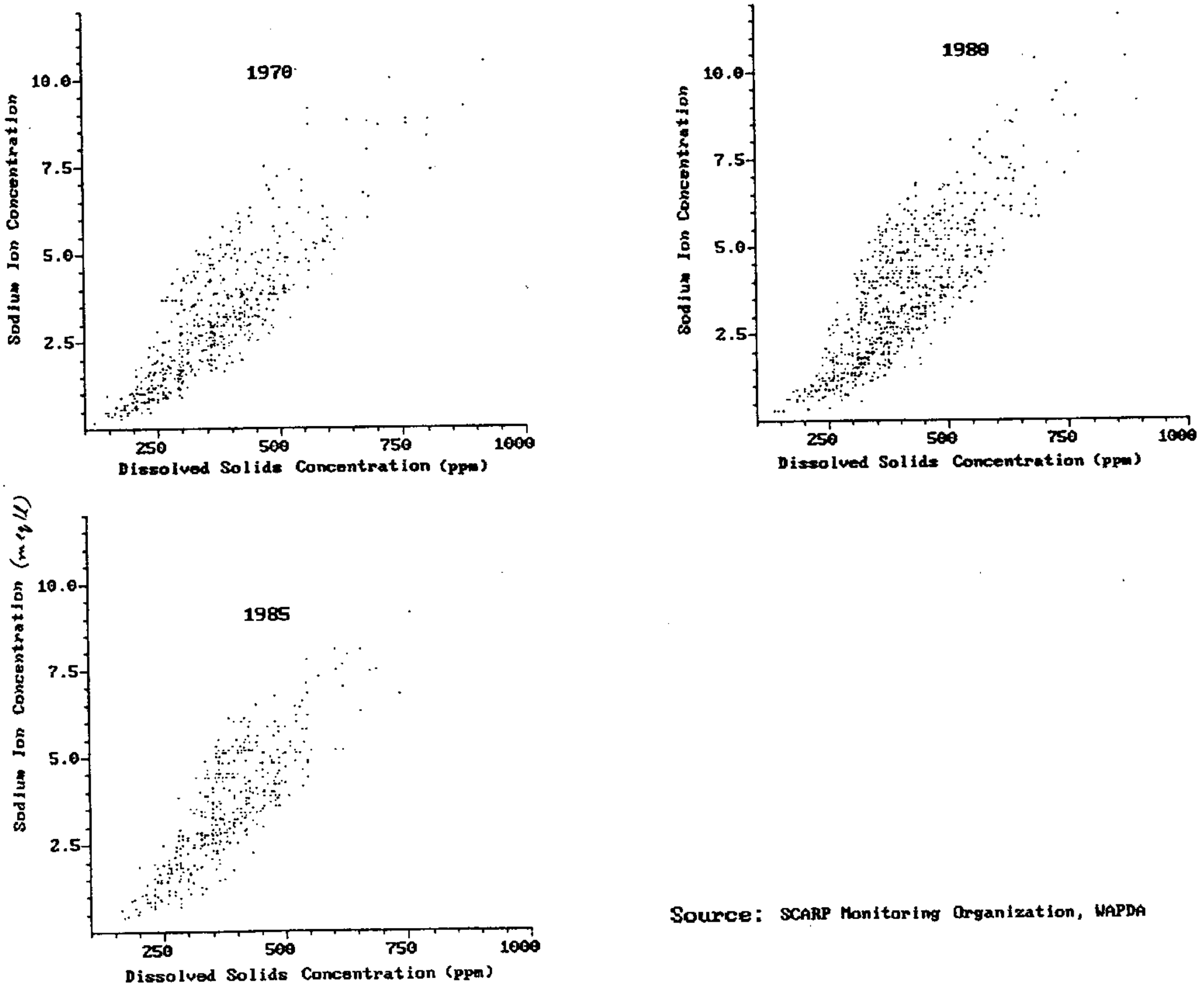
Source: SCARP Monitoring Organization, WAPDA

Figure 42 Salinity Control and Reclamation Project (SCARP) IV; Temporal Comparison of Groundwater Quality, Rechna Doab, Punjab, Pakistan.



Source: SCARP Monitoring Organization, WAPDA

Figure 43 Electrical Conductivity Response Over Time for Varying Salt Concentrations, Rechna Doab, Punjab, Pakistan.



Source: SCARP Monitoring Organization, WAPDA

Figure 44 Temporal Changes in Sodium Ion with respect to Increasing Salts Concentration in SCARP-IV, Rechna Doab, Punjab, Pakistan.

in supply is most acute for the period November-March. Despite the fact that almost two-thirds of the URR is non-perennial, the cropping intensity is in excess of 140%, which is more than the intensities achieved in the SCARPs I & IV (Figure 27, page 73). The cropping intensities in the distributaries of the LCC system covering the URR are somewhat less due to a higher incidence of culturable waste.

The alluvial complex consists primarily of fine to medium sand, silt and clay. The porosity of water bearing material ranges from 35-45 percent with an average specific yield of about 14%. The transmissivity ranges between 0.016 to 0.068 sq. m/s with an average of 0.034 sq. m/s. Based on the water quality sampling by WASID and Project Planning Organization (PPO (NZ)) of test holes/wells within the URR (1960 & 75), the deep aquifer conditions are classified to be predominantly fresh to slightly saline in the eastern and southern parts of the URR (Figure 45). In the eastern part, saline aquifer conditions have been observed for the area buttressed between the MR and BRBD Link channels, whereas to the south similar a situation is observed in the tail commands of the Nowshera Distributary offtaking from UCC.

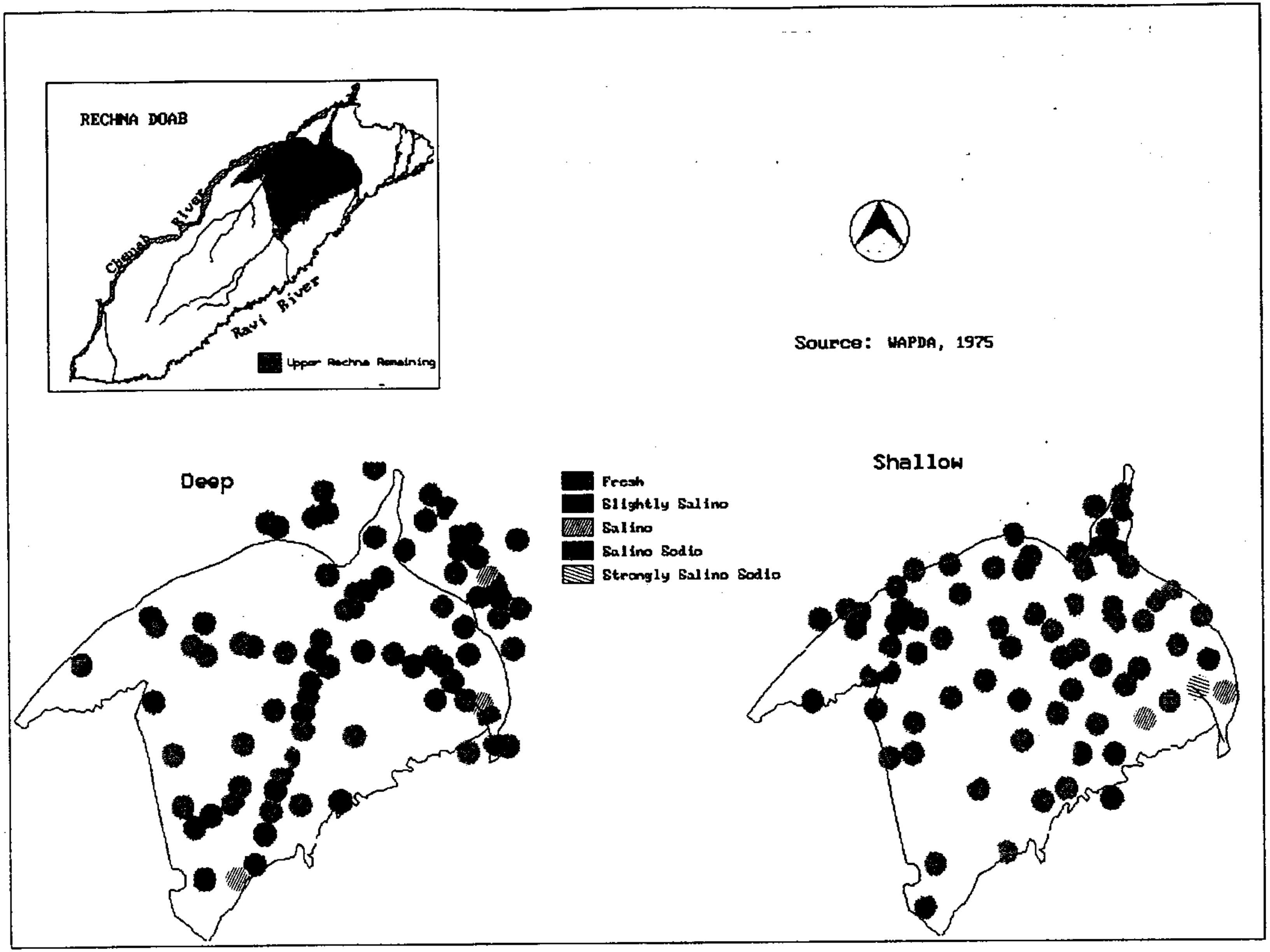
The shallow water quality in the URR, based on PPO (NZ) sampling in the mid 1970s, shows the spatial distribution of the fresh water zone to be even more expansive as compared to the similarly reported sites across the deeper aquifer. However, the areas along either side of the BRBD Link Canal in the lower stretch are shown to be saline to strongly saline sodic with an adjusted SAR > 9. These areas are in the non-perennial command of the Link Canal where the finer soil textures could be a compounding factor towards sodicity affectation (SSoP's soil classification reports the presence of Satghara (soil series) and its undifferentiated groups in this area that are highly saline sodic, see Figure 10, page 42).

A ranking study done by the PPO(NZ) for the *public* tubewells installed in the URR indicated that none of them was being used for the disposal of the drainage; instead, their utilization was to supplement existing canal supplies. However, the annual utilization rates (<15%) are lesser than the lower reaches of the doab due to higher contributions from rainfall.

a) Natural and Artificial Drainage

The project area has three main drainage basins both Deg Nala and Q-B Link for drainage to the Ravi River; and Ahmedpur Vagh to the Chenab River. The Q-B Link and Ahmedpur Vagh basins have drains that are mostly artificial and do not efficiently drain the area during the monsoon season.

The ***Deg Nala Basin*** in the Upper Rechna has the Deg Nala as the spinal drain that collects surface runoff and flows from several ill-defined channels. The length of these channels within Upper Rechna is 393 kms (211 kms natural) that ultimately dispose to the Deg



Source: WAPDA, 1975

Figure 45 Groundwater Quality in the Upper Rechna Remaining Project, Rechna Doab, Punjab, Pakistan.

Diversion Channel discharging into the Ravi River upstream of the Balloki Barrage. River Ravi, whose bed is only a few feet below the surrounding terrain, when at high stage, renders the outfall of Deg Diversion Channel ineffective. Consequently, the Deg Stage I work under URR includes the remodelling of the Deg Diversion Channel outfall into the Ravi River.

Drainage channels in the Deg Nala Basin are primarily to transmit surface runoff received from across the MR and BRBD Link canals. For the protection of the MR Link and BRBD, cross drainage works have been provided and an additional 183 Km of artificial drains cover sheet-runoff from damaging the UCC and collectively discharge into the Nikki Deg natural drainage channel. However still, at many places, the construction of roads and canals cross the path of the drainage. For overflows resulting from storms of higher intensity than designed for the cross drainage structures, the damage to the rice crop is substantial.

Similarly, the cross drainage works provided under the BRBD Link to handle water coming across the MR Link and areas between the two links are inadequate. Their inadequacy is further accentuated because the channels receiving water from across the BRBD are either non-existent or inadequate. This results in considerable ponding both above and below the BRBD Link Canal.

The ***Q-B Link Drainage Basin*** has a total drainage area of 3,100 sq km comprising the Sangowali, Mangoke, Sheikhupura, and Gujranwala as the main drainage systems. Although this basin has a well spread network of main and tributary drains measuring nearly 500 kms, but is still inadequate for surface runoff. Based on the observations by the PID and the local cultivators, the current drainage capacity has limitations with respect to storm runoff. In most of the area, the drains are designed at 0.04 cumecs/sq.km which is equivalent to a return period of 2.33 years, which is insufficient to accommodate a 5 year storm of 24 hrs duration. The more typical surface runoff for 5 year frequency and 24 hrs storm duration in the Q-B Link and Ahmedpur Vagh basins of Upper Rechna varies from 0.08-0.22 cumecs with an average of 0.15 cumecs/sq. km.

b) Soil Salinity

For the URR, the integrated assessment of salinity, as reported by the government agencies, indicates the following position:

	SSoP (1965-68)	Irrigation Deptt. (1974-75)	WAPDA MPR (1977)
Salt free	81%	84%	84.5%
Saline Soils	18.4	14.6%	13.9%

The incidence of surface salinity ***in the command of the LCC*** within URR, where the culturable waste is higher, is as follows (1975):

Channel	Class S3	Class S4
Gajargola	41%	50%
Vanike	33%	19%
Manchar	12%	

For the 2140 bore hole locations in the URR, a comparison of the WASID and MPR survey indicates that the top soil (0-6 in) non-saline land increased from 75% to 88% and accordingly the incidence of saline-alkali and non-saline alkali soils has also decreased.

For the URR, the normal soils as reported by the SSoP are further subdivided into well drained (48.5%), moderately well drained (24.5%), and imperfectly drained soils (8.2%). These soils are non-calcareous to slightly calcareous.

The saline-sodic soils are also divided into two categories; dense saline-sodic (15%) and porous saline-sodic (3.4%). The dense saline-sodic soils with a 60-130 cm thick B horizon are non-calcareous to strongly calcareous. The porous saline-sodic soils are moderately calcareous and comprise silty clay, silty clay loam, silt loam and loam.

c) Agriculture

Only one-third of the gross area of Upper Rechna is under perennial supplies, and that too only from UCC. Hence, much of the cultivation derives sustenance from the dominantly fresh shallow and deep groundwater pumpage based on tubewell densities that are one of the highest across the doab. Additional root zone requirements are met by rainfall which is about 3 times the magnitude in the southern reaches of the interfluve. The Rabi season cropping intensities are invariably higher with wheat as the dominant crop, whereas rice and sugarcane consume most of the irrigation water available during the Kharif. A comparison of the historical trends in *production* and *area* devoted to the major crops in the system is provided by the statistics compiled at the civil administrative level. For the districts of Gujranwala and Sialkot that dominate the Upper Rechna, the trends in wheat, rice, cotton, and sugarcane are provided under Figures 46-49.

The progressive and somewhat steady increases in the areal distribution of wheat since the mid- 1970s seem to have been interrupted towards the end of the reporting period across both the districts. The trends in production have largely been on the positive side, but highly erratic, with the sharpest decrease occurring in 1986-87. In fact, a comparison with other major crops in the districts indicates wheat has the highest mismatch between the cultivated area and the production, with the latter being quite sensitive to any change in the former. Towards the latter half of the eighties and early part of the next decade, these fluctuations are replaced by an incremental trend, thereby indicating a predictable response to increase in its area.

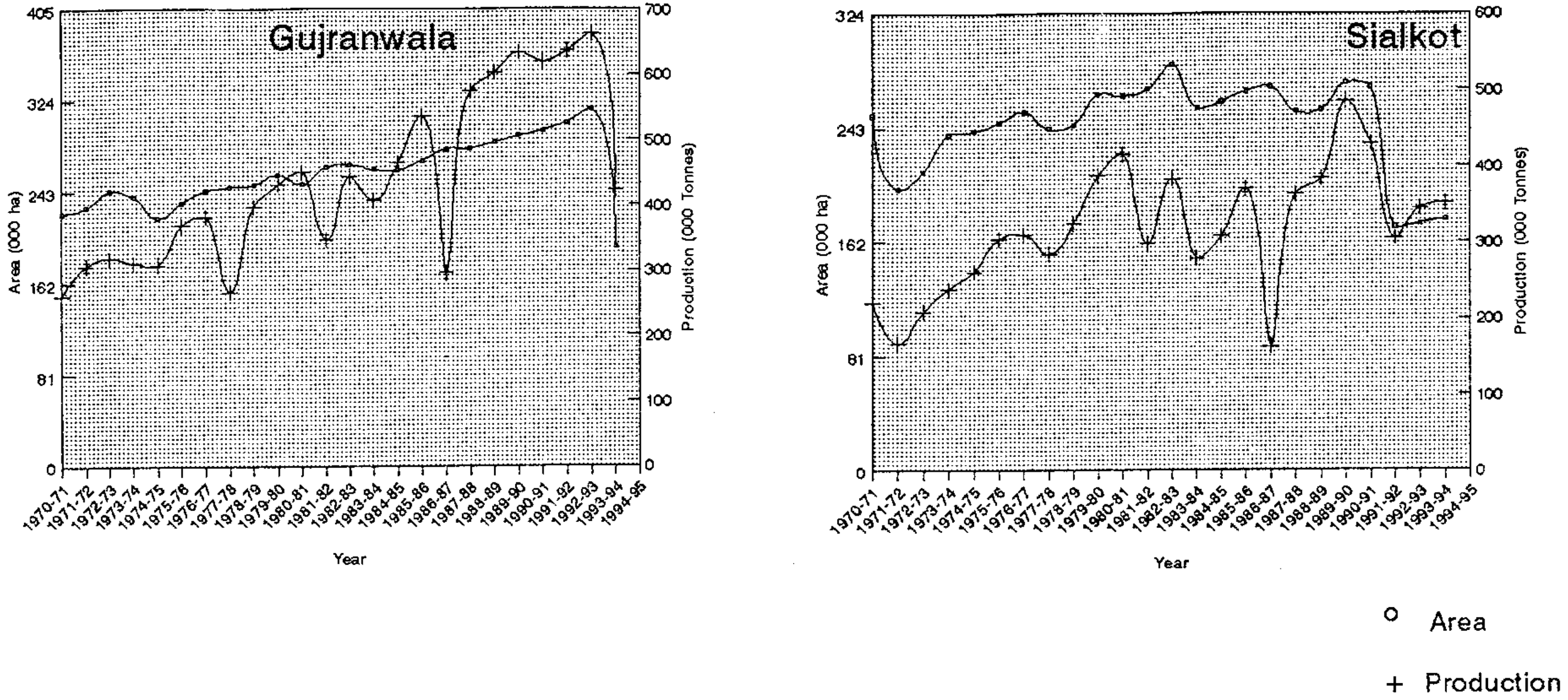


Figure 46 Temporal Comparison of Area and Production of Wheat for Districts in Upper Rechna Doab, Punjab, Pakistan.

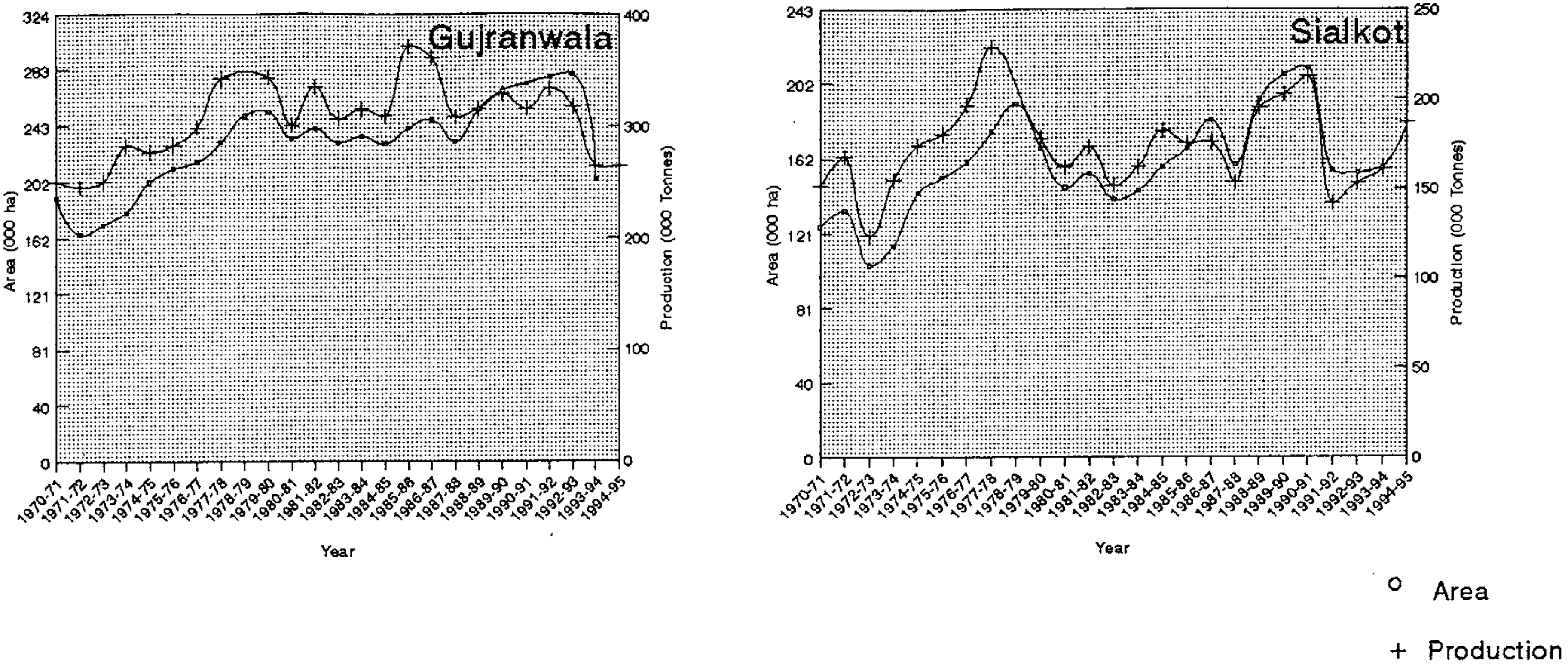


Figure 47 Temporal Comparison of Area and Production of Rice for Districts in Upper Rechna Doab, Punjab, Pakistan.

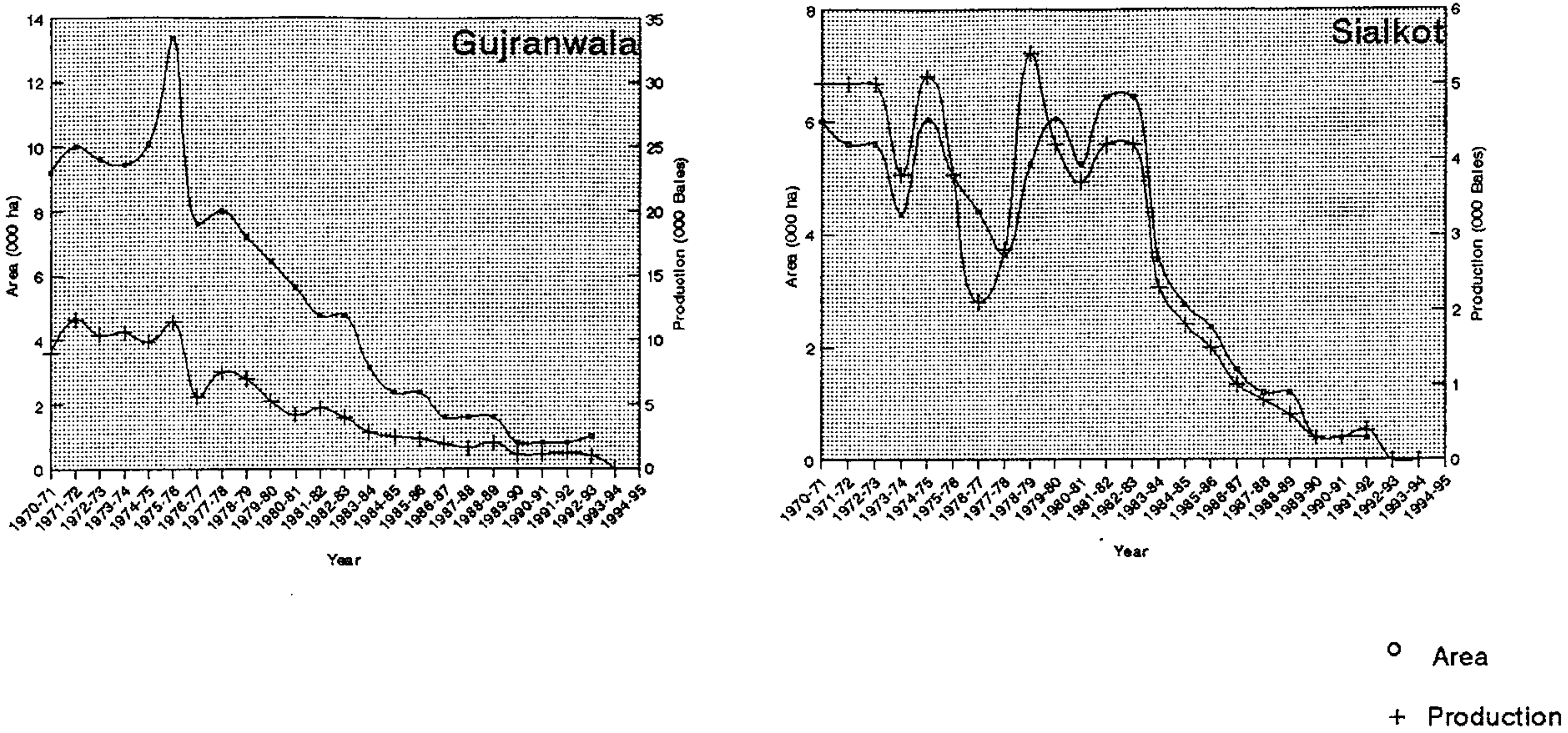


Figure 48 Temporal Comparison of Area and Production of Cotton for Districts in Upper Rechna Doab, Punjab, Pakistan.

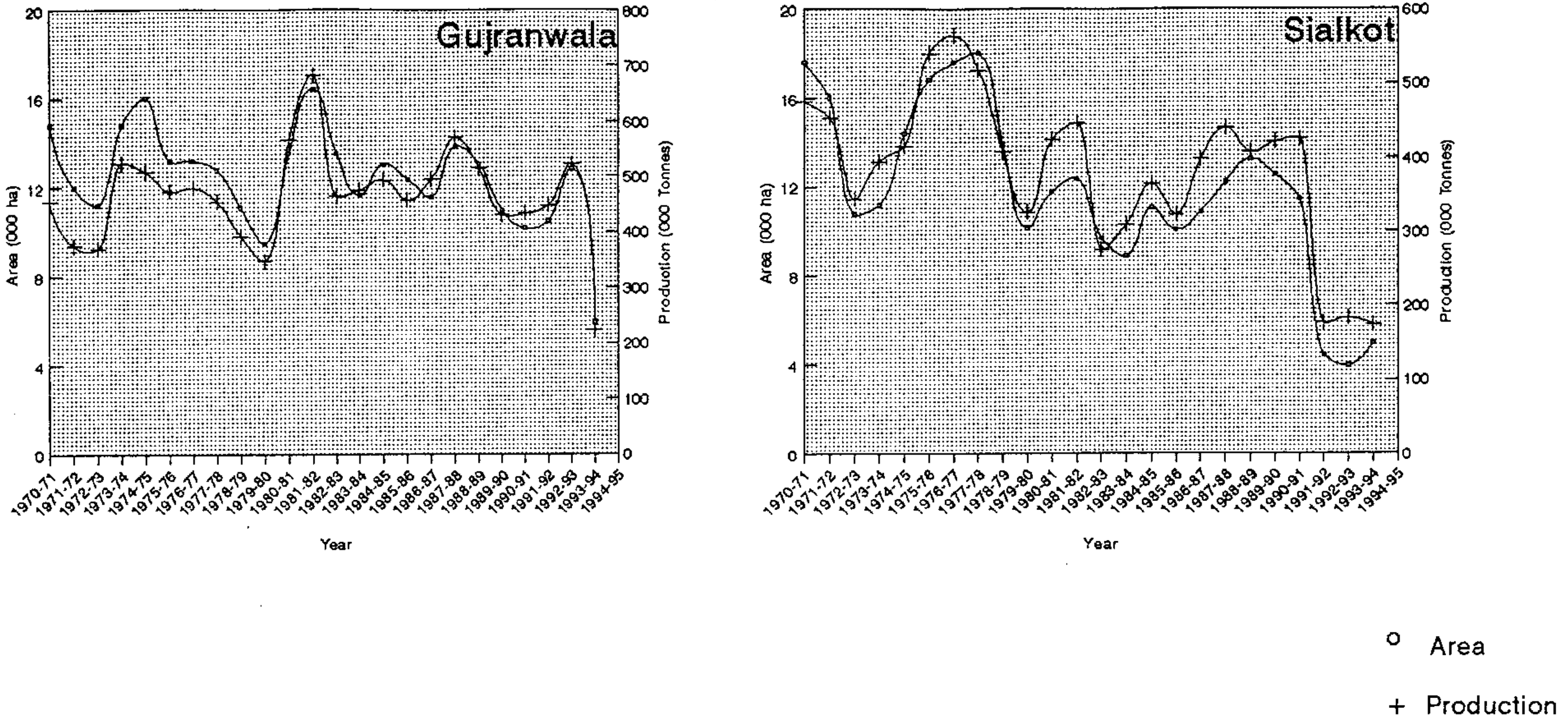


Figure 49 Temporal Comparison of Area and Production of Sugarcane for Districts in Upper Rechna Doab, Punjab, Pakistan.

A closer examination of these fluctuations for two districts indicates their respective trends to be largely synonymous across time. For the Gujranwala District, the best ratio of increase in production per unit increase in area occurs in the mid 1980s, whereas for the Sialkot District there are two distinct periods corresponding roughly to the second halves of 1970s and 1980s. The large variability across this ratio for both of the districts exposes the large gaps in the potential productive capacity that are further compounded by extremely variant changes in these levels. The loss in production from 1992 onwards has partly to do with the reduction in flows within the UCC system following the Apportionment Accord that has also significantly affected the cultivation of other major crops within the area.

With the fine textured soils dominating the Upper Rechna, the cultivation of rice during the plentiful flows of Kharif dominates the cropping pattern within the area. Moreover, its production, just like sugarcane, closely follows its areal extent, thereby indicating a relatively uniform mix of varietal and cultivation practices across equally uniform soil conditions. In no uncertain terms, the observed increase in rice area between 1971-1993 has been 15-20% higher than wheat, especially during the seventies decade, when extensive tubewell development occurred within the area. And much of this preference for wheat and rice has seen the gradual near-eliminaton of cotton from the area beginning in the early eighties.

4) Lower Rechna (SCARP-V)

The earliest reclamation strategy for Lower Rechna was planned by WAPDA consultants M/s Tipton and Kalmbach in 1966. It comprised a gross area of over 1.1 Mha of which 0.85 Mha was culturable. For SCARP-V, a gross area of 0.803 Mha of which 0.728 Mha was canal commanded by Jhang, Rakh, Lower Gugera, and Burala branches and the remaining by Haveli Canal and Koranga Feeder of Central Bari Doab Canal. At that time, nearly 20% of the area was recognized as affected by soil salinity and waterlogging, and virtually the entire area was under-irrigated for optimum crop production. The benefits from SCARP-V would have primarily derived from an increase in cropping intensity from 114% to 135%.

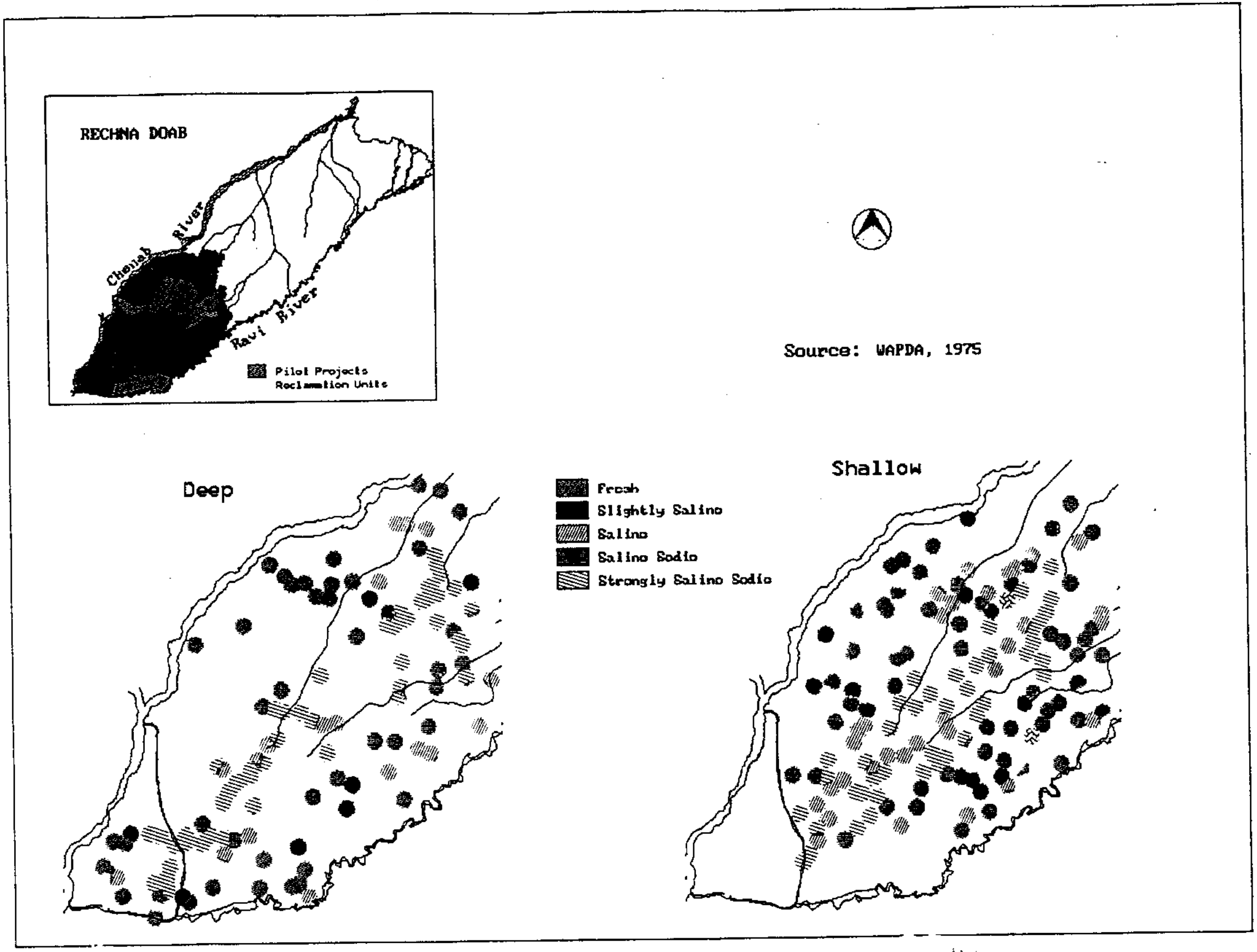
The strategy for the development of the Lower Rechna Project encompassed utilization of marginal quality ground water and the net transfer of 28,600 hm (out of 90,000 hm of total diversion) of surface water supplies from the Upper Rechna SCARP-IV (compensated through the extensive development of FGW). Although it was recognized that the marginal groundwater (1500-3000 ppm) would result in slightly reduced crops yields, the economic benefits accruing from the availabilty of water for extensive agriculture would overweigh the prohibitions resulting from scarcity of water. The necessity for the drainage of saline water was overlooked on the basis of the recomendation put forward in the Revelle Report (1964) and the Regional Plan for the Development of Northern Indus Plains (Tipton and Kalmbach Inc., 1966). Subsequently, on the recommendations of the World Bank, the project, as a whole, was defered and its lower part under the commands of Haveli, Koranga Feeder, and the tail reaches of the LCC system was renamed and planned as ***Shorkot Kamalia*** Unit of SCARP-V comprising 0.172 Mha.

The draft report was prepared by M/s Tipton and Kalmbach Inc. in 1970 with the same concept as already indicated above. Because of the delay in implementation and the desire to incorporate the experiences from operating SCARPs, the draft report necessitated an update. The project was assigned to M/s Republic Engineering Corporation for the preparation of the revised planning report. As an early action plan, the consultants prepared a planning report, covering a gross area of 68,400 ha termed as "pilot area" during 1974. In pursuance thereof, 101 tubewells were installed to alleviate the problem of waterlogging and salinity. A Project Planning Report by M/s Republic Engineering Corporation covering the entire Shorkot Kamalia Unit was finally submitted in 1976, one year after the inception of the project.

The remaining part of SCARP-V (LRR Project) was assigned to the Project Planning Organization (PPO) Northern Zone (NZ) in 1974 for the preparation of a revised plan. In view of the severity of the drainage problem, a PC-1 performa for a part of the project covering a gross area of 73,650 Mha and termed as ***Satiana Pilot Project*** was submitted in December 1975. The pilot project envisaged the construction of 71 drainage tubewells as an interim measure to provide immediate relief (see location in Figure 22). This is part of the overall plan for the LRR project comprising six drainage sub-projects, including Khairwala Unit.

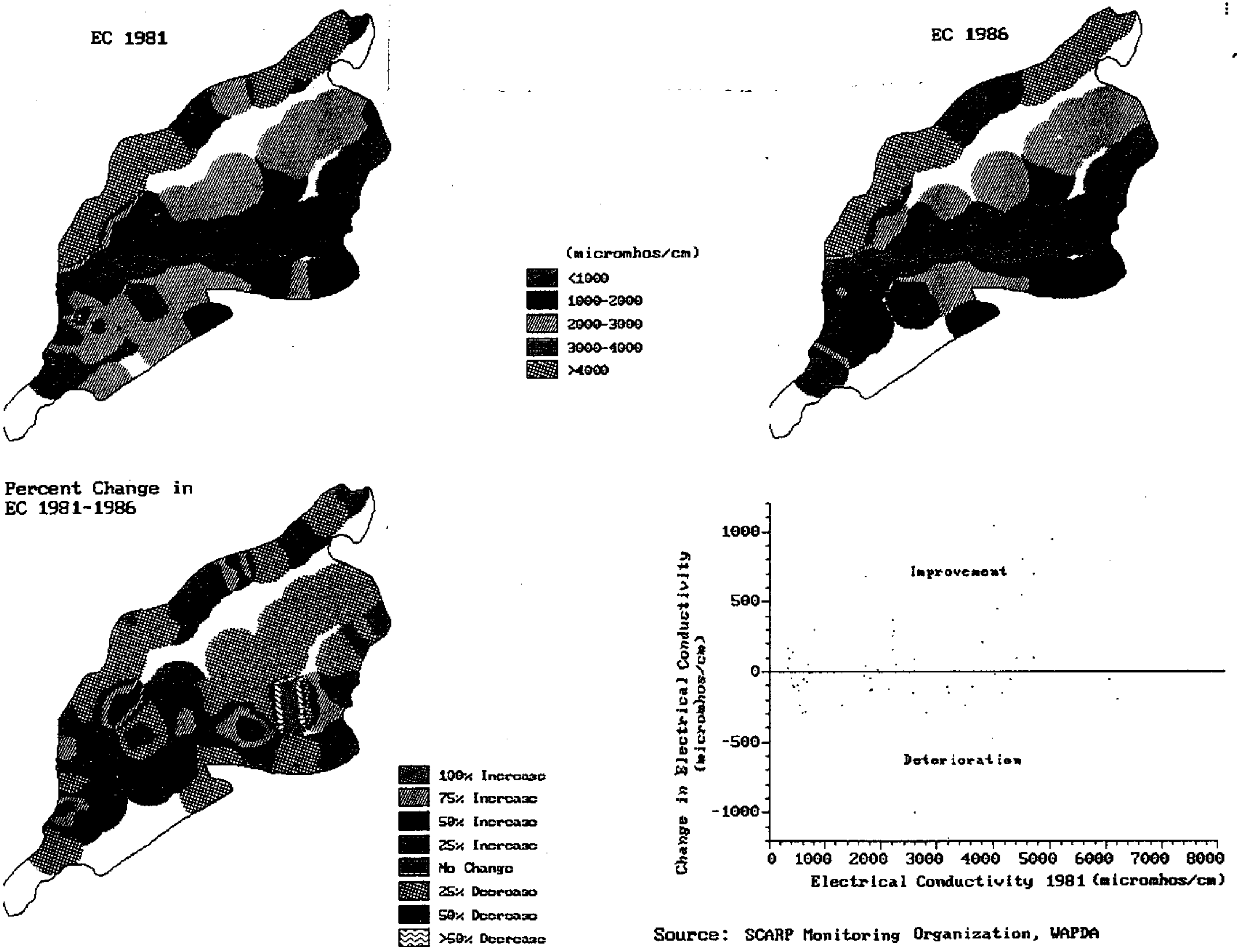
At the time of planning for the Satiana Pilot Project, the Agricultural Census Commission identified nearly 8500 tubewells in LRR of which over 5300 were in the useable groundwater zone and the remaining in the saline groundwater zone. The tubewells, 35% of them electric, were 80-140 feet deep with an average discharge capacity of 1 cusec. The overall groundwater quality picture was based on the results of the WASID test holes and wells drilled in the area during the early 1960s followed by the PPO (NZ) sampling during the mid-1970s (Figure 50). Strongly saline-sodic waters in the deep aquifer are confined to a continuum along the central longitudinal axis of the doab; towards the Chenab River the quality improves to fresh water however progressing towards the Ravi River results in variant stratifications of saline- to saline-sodic conditions within the aquifer. Exceptions to these higher salinity profiles occur in the immediate vicinity of the Ravi River, such as the alluvial formations beneath the Kamalia Plain where the water quality is fresh to a depth of 100 meters or more.

After the commissioning of the Satiana drainage tubewells, data from water quality monitoring of the 69 wells indicates electrical conductivity values to be lower (< 1000 micromhos/cm) only in the center of the project area along the path of the Lower Gugera channel; much of the area around this belt has EC values exceeding 2000 micromhos/cm (Figure 51). Changes in the quality across six years of pumpage indicate that areas below the fresh water recharge zone of the Lower Gugera have improved by as much as 100% over the situation in 1981; the lower reach of the channel in the project area do not exhibit any particular change in EC values. Interestingly, the situation seems to have improved towards the edges of the Project area, though its magnitude remains in excess of 4000 micromhos/cm.



Source: WAPDA, 1975

Figure 50 Groundwater Quality in the Lower Rechna Remaining Project, Rechna Doab, Punjab, Pakistan.



Source: SCARP Monitoring Organization, WAPDA

Figure 51 Temporal Comparison of Changes in Electrical Conductivity of Groundwater in the Satiana Pilot Project, Rechna Doab, Punjab, Pakistan.

In comparison to the groundwater salinity concentrations in the range 2000-3000 micromhos/cm along the length of the Burala channel in the south of the Project area, there are indications that a 25% decrease in the concentrations has lowered the salinity levels to below 2000 micromhos/cm.

The watertable condition in the Faisalabad and Toba Tek Singh areas indicated worsening of the affectation due to waterlogging. The rate of rise of watertable in the useable groundwater area of LRR was either negligible or negative, whereas in saline groundwater areas it was increasing. The PPO (NZ) proposal (1980) recommended surface and subsurface drainage for the Faisalabad area. In Toba Tek Singh unit, the subsurface drainage was required for the affected areas along the Darsana Distributary only; the drainage along the TS Link was completed against a separate proposal under **TSMB Link Canal Drainage Project**.

For the subsurface drainage proposal submitted by PPO (NZ) for Faisalabad, it was realized that most of the area was underlain by saline groundwater not fit for direct use even after mixing. In the absence of a natural drainage network, the logical choice for disposal of the effluent was in the surface drainage system or existing canals.

PPO's calculations towards a workable limit for safe disposal of this effluent into the irrigation network considered a maximum threshold of mixed water quality around 750 micromhos per cm. These calculations were based on the placement of discharging tubewells along suitable lengths of canal system but not exceeding 70 lps of discharge at any point. Similar calculations for the saline effluent of drainage tubewells installed along various drains for ultimate disposal into the Chenab River above Trimmu Barrage had a threshold value of 595 micromhos/cm (assuming a mixing ratio of 1:34).

During the early 1980s, in consultation with the World Bank, WAPDA decided in favor of tile drainage for the 30,350 ha of "disaster" area in Faisalabad. This was contrary to the planning executed under the PPO (NZ) proposal for tubewell drainage referred to above. The main reason for the switch seemed to be the expectation that with tile drainage the level of salinity in the shallow waters will be reduced eventually. Consequently, ***Drainage IV*** project was launched in 1983 to reclaim high water from 119,000 ha of land; this included the subsurface drainage component on areas with water < 1.5 m. The Project activities were split in two different areas to the north and south of the Faisalabad city (Figure 52). For the tile drainage part, the PVC pipes at depths between 1.8 - 3.8 m are discharging in a total of 79 sumps located 3-4 m below the ground surface. The Drainage IV subarea south of Faisalabad (Schedule I) overlaps with 15 tubewell sites that are part of the larger Satiana Pilot Project and draining into the Samundri Branch Drain.

With near completion of project activities in 1993, the watertable depths across much of the project area had decreased considerably (Figure 53). WAPDA's M&E Directorate data (SMO Staff, 1993) for the Drainage IV Project provides a mapped comparison of the changes in watertable in the pre- and post monsoon period of 1992 whereby much of the

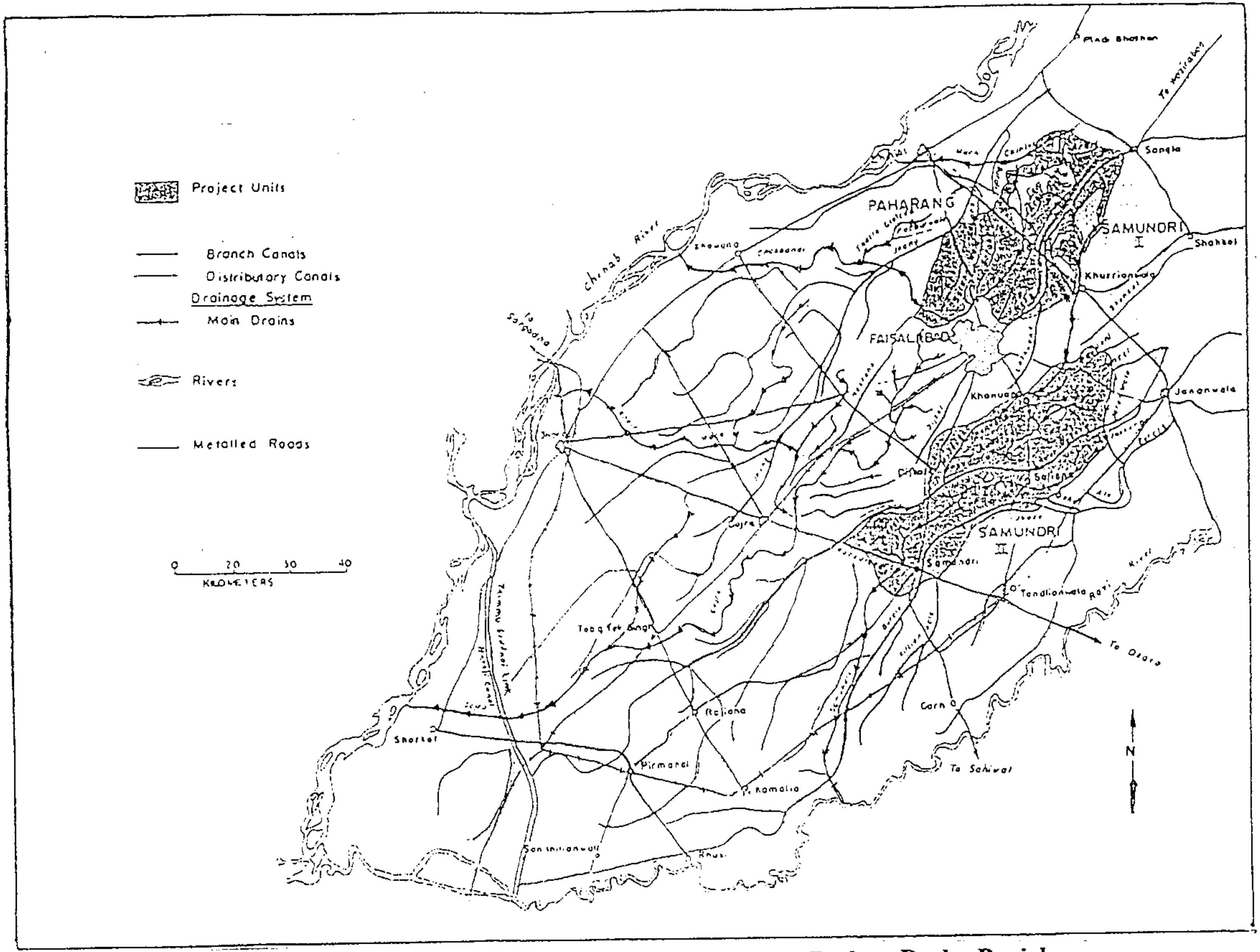
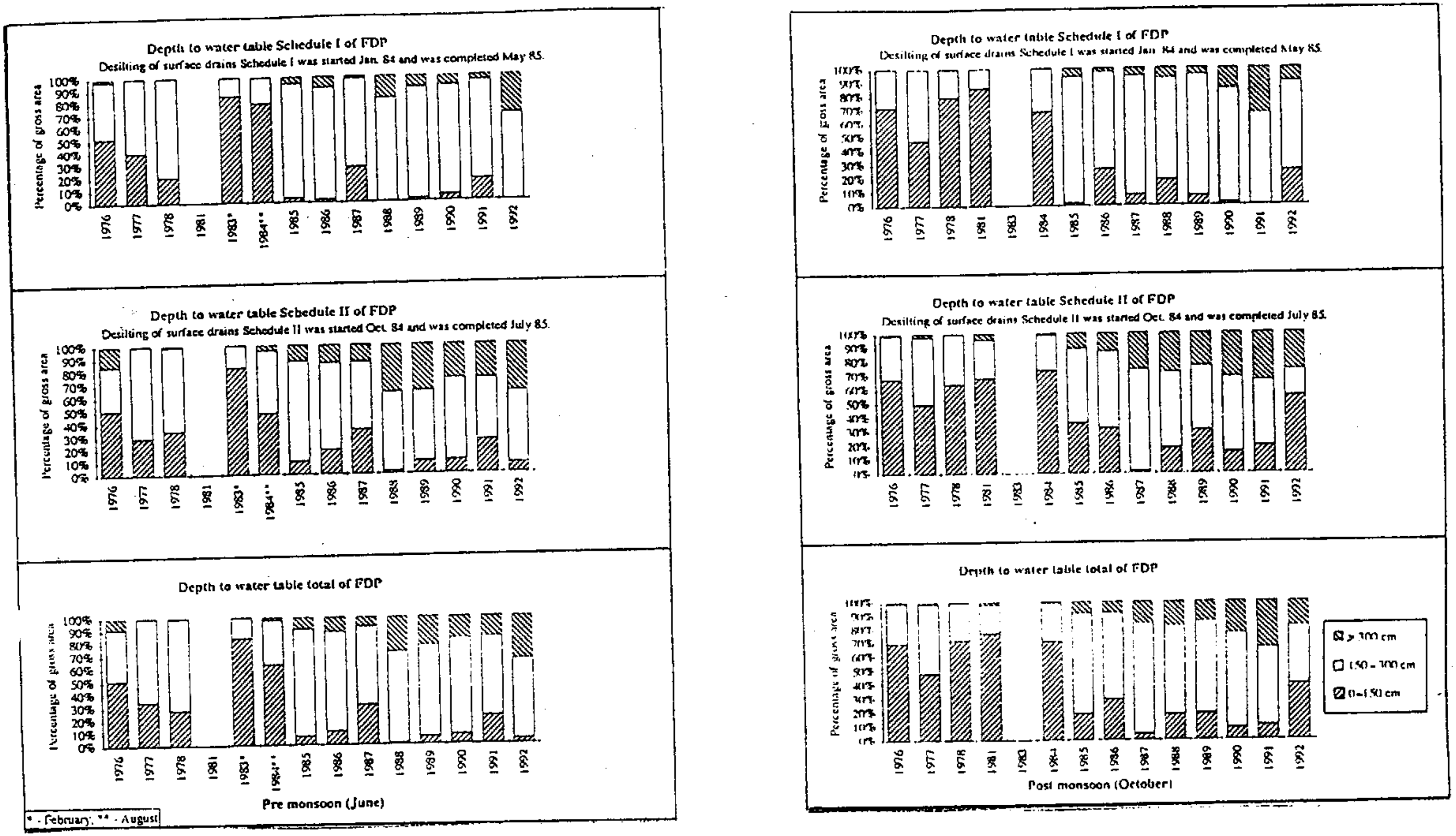


Figure 52 Location Map of Fourth Drainage Project, Rechna Doab, Punjab, Pakistan.



Remark: 1976 - 1984 data from Tubewell and Ground Water Monitoring Directorate (formerly Hydrologic Monitoring Directorate), 1985 - 1992 from M&E/SMO of FDP.

Figure 53 Percentage Variation in Depth to Watertable within the Fourth Drainage Project, Rechna Doab, Punjab, Pakistan.

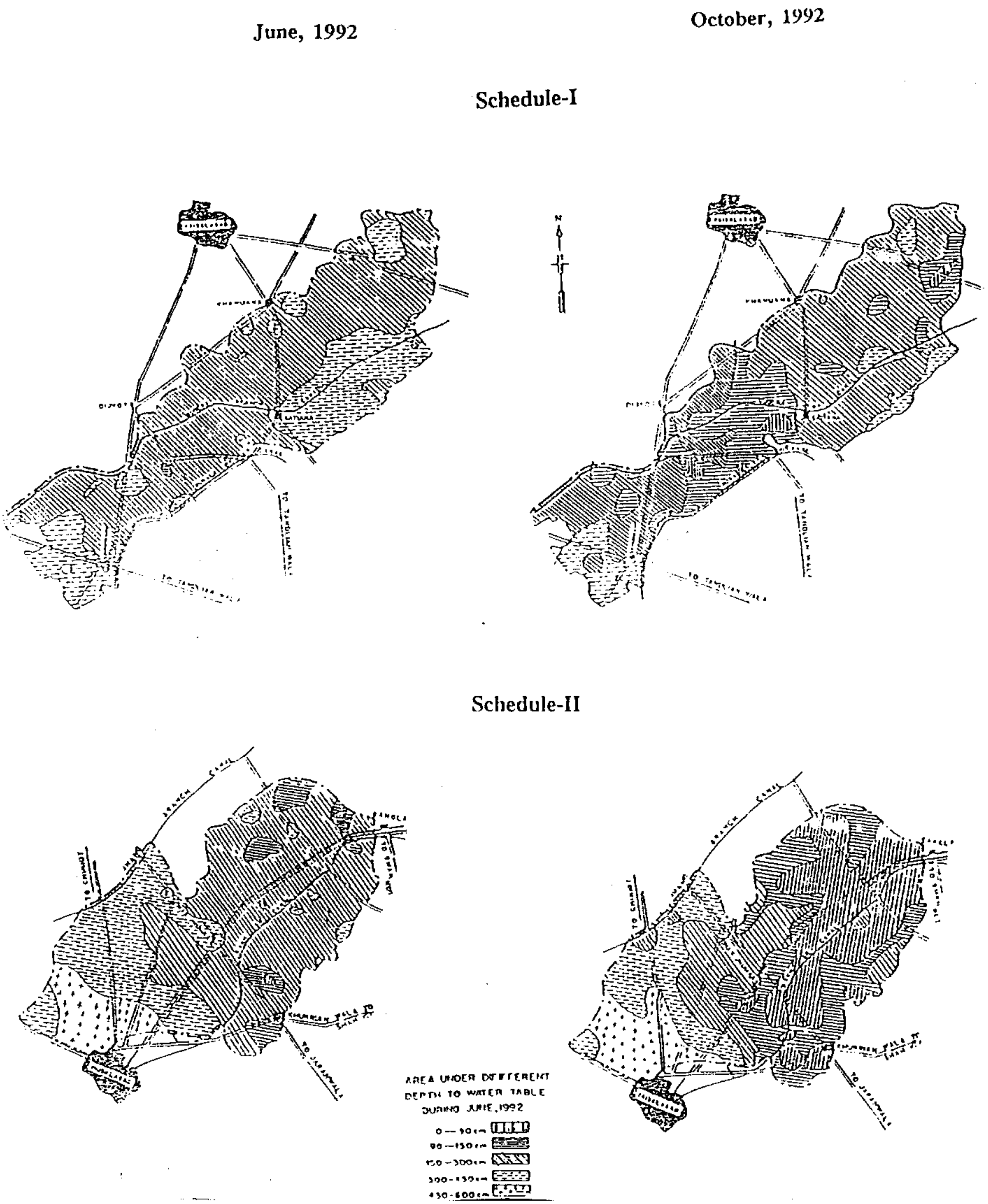
Schedule I locale has the watertable staying below 1.5 m depth (Figure 54). The situation in Schedule II is even better, especially in areas immediately northwards of Faisalabad. There are, however, areas on either side of the Rakh Branch that experience a drastic rise in watertable that reaches within the root zone.

While *deep water quality* could be inferred only for Schedule I from the tubewells of the Satiana Pilot Project, the monitoring of the piezometers installed by the SMO (WAPDA) shows no clear trend in *shallow water quality* towards improvement or deterioration (Figure 55). In fact, no systematic mapped representations are available to isolate any significant spatial trends. Geo-chemical analysis shows these waters to be predominantly (> 65%) rich in Na and Ca bicarbonate salts that are primarily responsible for values of RSC characterizing these waters as hazardous. Based on an annual planned pumpage of nearly 7,400 Hm from the sumps, the quality of the effluent approaches 44,000 ppm at the drains before outflow to the rivers.

Elsewhere, existing data on the quality of effluent from the SCARP-V drainage projects indicates an approximate salt load of 2 million tonnes likely to be disposed into the system (Table 26, page 96). The contribution is expected to be highest from **Shorkot Kamalia Saline Project** for a destination discharge quality of over 96,000 ppm into the TSMB outfall drain below Sidhnai Headworks. Its magnitude is seconded by the TSMB Link project drainage whose higher pumpage is compensated by a comparatively lower effluent load. In fact, at the time of planning for the TSMB Link Canal Project, an 8 Km wide belt on either side of the Link was proposed, which partly overlapped the Shorkot Kamalia Project (Project Report, 1975), but due to planning conflict with the latter it was not implemented.

As part of the drainage strategy developed by PPO (NZ) for LRR in 1980, the first phase of the ***Gojra Khewra* Project** comprising 40 SGW tubewells disposing into the two nearby distributaries and a surface carrier system and outfall drain was completed during 1986-88. For the second phase of the project, comprising 58 SGW tubewells and 303 kms of the Gojra surface drainage system as an extension of the Phase I carrier system, reclamation is planned for a total project CCA of 0.165 Mha of which 27% has a watertable of less than 2.1 m and 14% has saline soils. The Project aims to bring back into production 2,500 ha of abandoned land, 15,200 ha of waterlogged land, and increase yields over an area of 44,500 ha.

The outfall of the Gojra Khewra drainage effluent is the Chenab River through the Gojra Main Drain carryover across the Haveli and TS Link channels; the Khairwala surface drainage system discharges upstream of the city of Jhang and also supports the disposal for the Faisalabad area through the Nasrana and Dijkot Branch Drains (see Figure 19 for location). To accommodate these flows, the Khairwala Drainage Unit Channel capacity was designed at 22 lps/square km runoff which corresponds to an 8-year return period. The structures on the network (e.g. siphons, falls, and bridges) are designed for double this capacity.


June, 1992

October, 1992

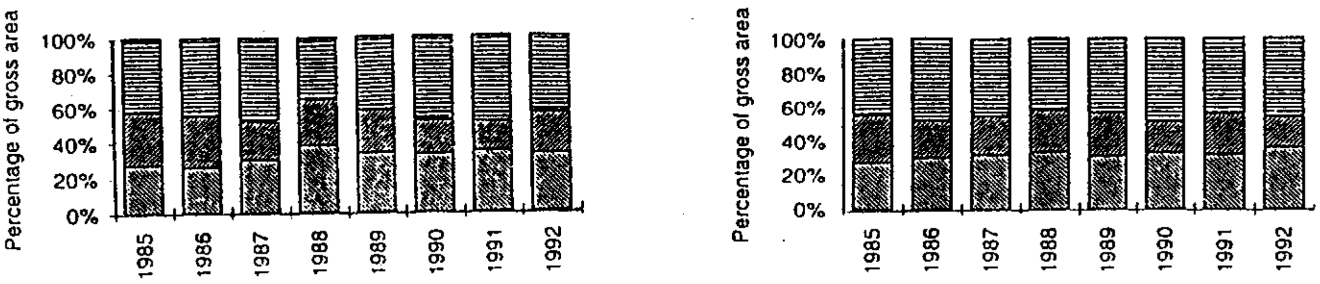
Schedule-I

Schedule-II

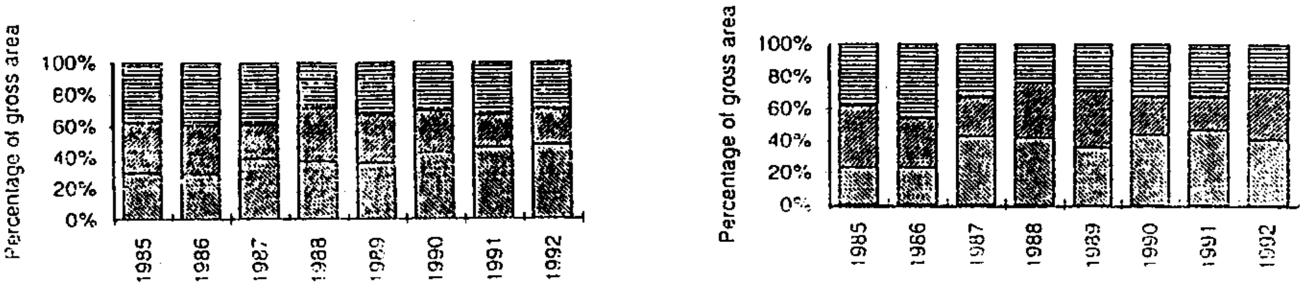
Figure 54 Location of Change in Depth to Watertable within the Fourth Drainage Project Schedules I & II, Rechna Doab, Punjab, Pakistan.

Source: SMO, 1993a

Shallow water quality Schedule I of FDP



Shallow water quality Schedule II of FDP



Shallow water quality total of FDP

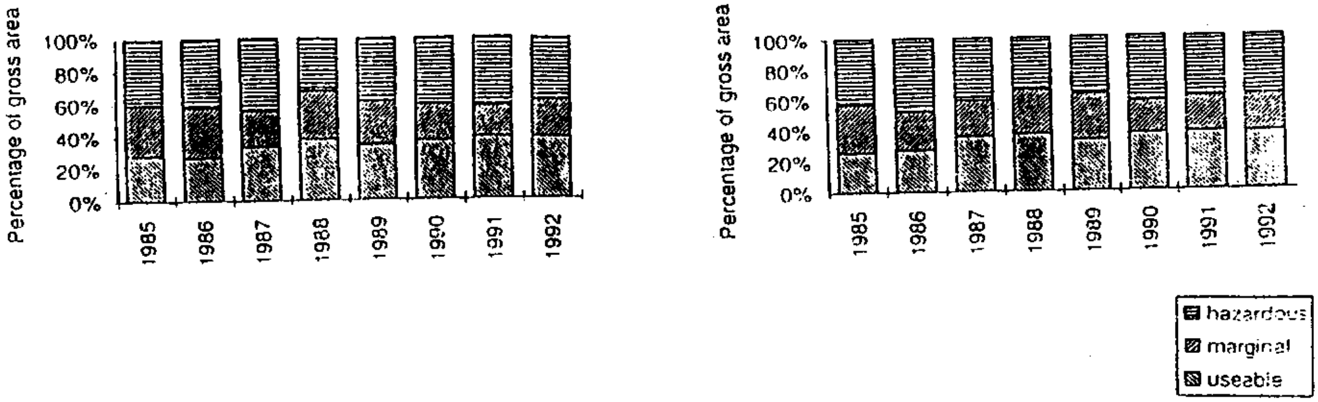


Figure 55 Variation in Shallow Groundwater Quality within the Fourth Drainage Project, Rechna Doab, Punjab, Pakistan.

X. EMERGENT MANAGEMENT EXPEDIENCIES: IIMI'S PERSPECTIVE

With over a hundred years of history in the realm of irrigated agriculture, the system-wide gains across the Rechna Doab have been of fundamental importance for comparative undertakings elsewhere. As the system has matured in productivity and deliverance of sustainable goods across multiple agroecological zones, so have its ailments that have been relatively easy to identify but tough to cure. The multiplicity of problem definitions, brought about by the diversity of the physical and crop related constraints, have nurtured synthesis strategies with increasingly focused solutions. It would be rational to expect unilateral solutions to have limited applicability and a host of misgivings in perspective. There have been numerous public sector forays into rapid intensification and reclamation of the irrigated lands, all within the system-level constraints inherited since the Raj days, and further advancements to continuing sustainability seem to be bordering on arbitrary and piece-meal initiatives. While much of the policy discourse has seen reasonable articulation through the WSIPS formulations (awaiting respective capital outlays), the demands inherent to non-capital intensive gains are subsumed by management strategies that are closer to realizations at the farm level. Inasmuch as the research undertakings bring to fore the pressing causes of regime instability, their contributions to emergent mass of information facilitates straining of the (capital and non-capital intensive) options for public sector investments.

For the Rechna Doab, IIMI's research contributions to irrigated agriculture have been limited in space but significant in the scope of undertakings. With a streamlined focus on mainly distributary and watercourse level management concerns, the operational nexus could be broadly categorized under the following:

- Performance of the surface distribution system;
- Identification of incipient salinity on the farms; and
- Quantity and quality of the groundwater for conjunctive use.

In developing the appropriate strategies for systematic monitoring and research, IIMI's choice of the sample watercourses (41) was scattered across the Upper and Lower Gugera Irrigation Divisions of the LCC East Circle so as to encompass the contrasting hydrologic environment with respect to the abovementioned categorizations. Notwithstanding the collection of the substantial mass of first hand information, IIMI's unbiased assessments provide useful insights into the system-level deficiencies constituting gaps in performance that have been doggedly remiss from the sector-level policy initiatives. The effectual contributions to the general pool of knowledge arising from studies on reclamation shoots, desilting campaigns, salt and water balance, channel calibration and simulation, water markets, warabandi, and hydraulic surveys constitute supplementary inputs to the focussed attentions listed above and for which the salient findings are provided as under.

A. Surface Irrigation Flows

Towards monitoring of the irrigation system performance in the LCC's secondary distribution system, IIMI's research objective was to identify management options having potential for increasing equity and reduce variability of flows. Variations from design levels in these flows cause differences in outlet discharges that invariably affect productivity per unit of land. For instance, based on IIMI's observations for the Lagar Distributary (Upper Gugera Division) and Pir Mahal Distributary (Lower Gugera Division), lapses in channel maintenance (degraded by siltation, cross-sectional enlargement) result in higher supply levels in the head reach outlets of the system (Figure 56). The disruption to tail reaches is aggravated if the channel receives <70% of the design flows (as would be the case due to fluctuations in the main canal). The situation is dramatically improved in the wake of channel maintenance through desilting, whereby even the tail end watercourses receive above design supplies (Figure 57). Similar observations elsewhere in the LCC East Circle are largely in agreement with the system-wide inequity patterns indicated above.

Interestingly, while the < 70% supply availability enforces a rotation on the tail distributaries of the Lower Gugera, the same fluctuations occurring across the Upper Gugera outlets continue to aggravate distribution along the respective distribution channels. Data obtained for several months in 1990 revealed significant inconsistencies in equitable distribution even when scheduled rotations are implemented, such as in the distributaries below the Bhagat head regulator of the Lower Gugera Canal. Pir Mahal Distributary operated about 40% of the time period below 70% rating for the channel capacity when receiving its share of supplies through rotation; this contrasts sharply with the near continuous operations of the neighboring Khikhi and Dabbanwala distributaries at 90% or more of authorised full supply.

An interesting observation relates to the implementation of the lining program by the OFWM in the command outlets across the LCC East, whereby watercourse beds are improved to accommodate modular flow conditions. When such improvements occur in the distributary head reaches, where due to siltation the outlets are already benefitting from a higher head, the result too often is an outlet discharge greater than sanctioned with a concomitant reduction in the downstream flows.

The implications are compounded further in lieu of the lining strategy following a top down approach whereby head and middle reach watercourses are getting a disproportionate share of lining as compared to the tail watercourses (field survey data for the Chuharkana Subdivision of Upper Gugera Division, 1988-89). This was substantiated by observations on the Lagar Distributary whereby every lined watercourse at the head was drawing 25-50% more than the corresponding ones without lining; moreover, all lined watercourses were located in the upper two-third of the channel. Similar behavior was also observed for the Pir Mahal Distributary at the tail of the system. Given a spatial refocussing of this emphasis to tail end watercourses would not only benefit as many farmers as before, but would also result in pronounced water savings in areas where they are needed more.

Figure 56a

Lagar Distributary
Water Distribution Equity

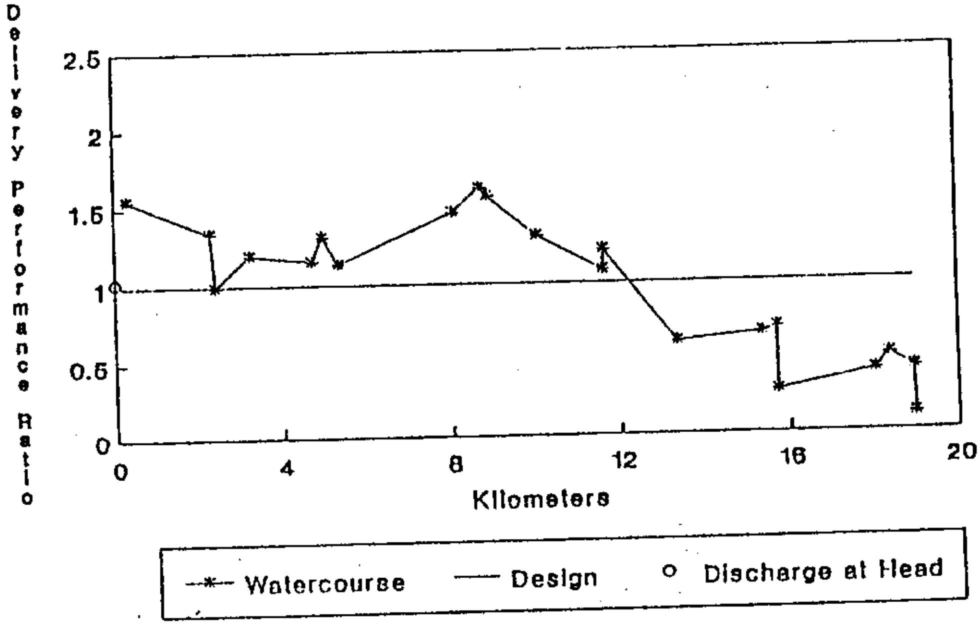


Figure. 56b

Pir Mahal Distributary
Water Distribution Equity

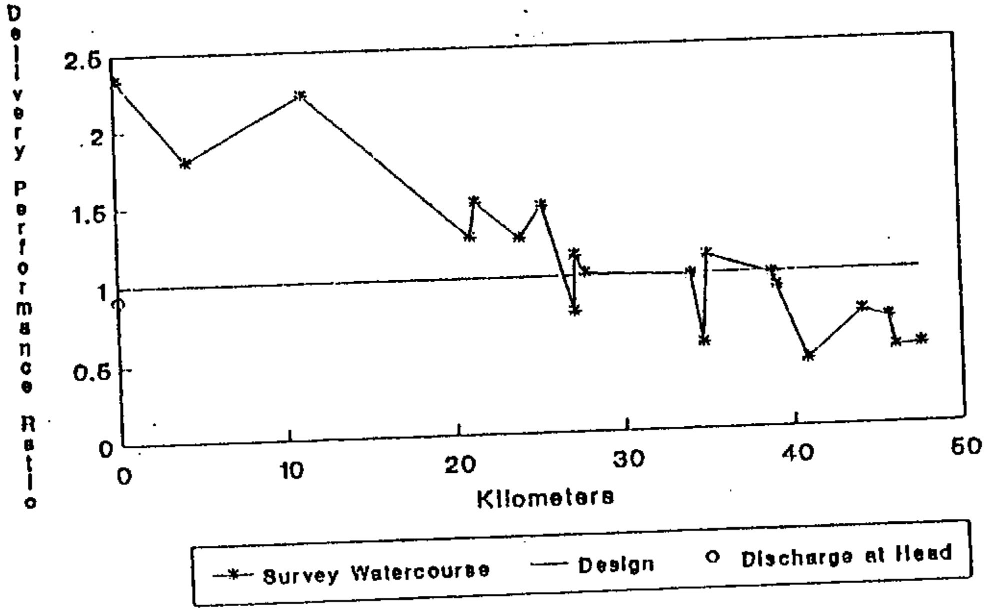


Figure 56 Water Distribution Equity in the Lagar and Pir Mahal Channels of the LCC System, Rechna Doab, Punjab, Pakistan.

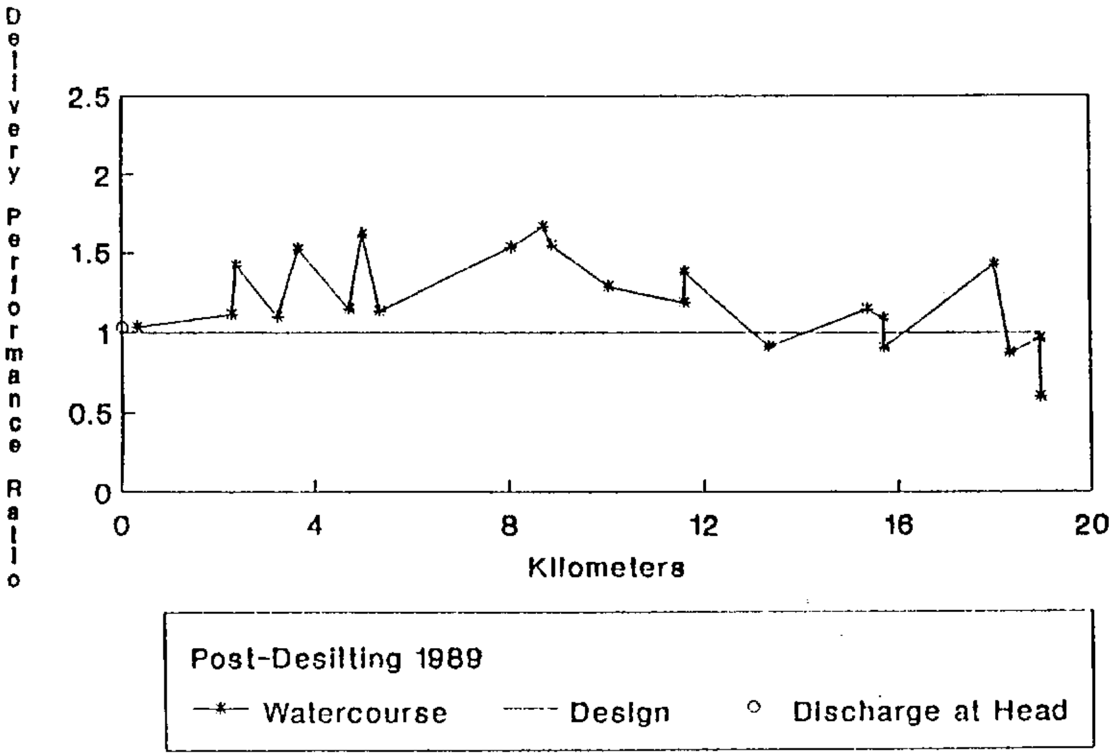


Figure 57 Improvement in the Flow Distribution to Outlets following the Desiltation in the Lagar Distributary of the LCC System, Rechna Doab, Punjab, Pakistan.

The variability of surface water supplied to the heads of outlets along distributaries exhibits a general spatial pattern that parallels that of equity in water distribution. That this variability increases with distance from the head, regardless of the channels location in the Gugera system, is due to the rigidity of the system to cope with uncontrolled flows and lack of channel maintenance-- traits common to many of the distributaries. Below the outlet, the variations could be brought about by mixing with substantial pumpage, irrigation of higher fields, poor watercourse maintenance, or improperly designed improvements.

Finally, research results from the LCC East confirm that careful management of head gate structures is necessary if distributary discharge variability is to be reduced to, and maintained at, the lowest practical levels. In the absence of reliable rating curves for the gauge reader, in many instances the near absence of such gauges, results in the regulation of head discharge being a matter of guesswork. Here, notwithstanding the gatekeepers experience, IIMI's observation data suggests that this variability could be better controlled than it is now.

B. Groundwater Harvest

1) Harbinger of Development

Extensive public groundwater development in Rechna Doab spurred two major, near simultaneous, changes in irrigated agriculture that soon spread throughout much of Punjab. A three- or four-fold increase in water supply at the water-course level meant that the low design (50-75 %) cropping intensities supported by the surface irrigation system could be exceeded. Annual cropping intensities in many LCC distributory commands rose rapidly to well over 100 percent. The greater abundance of water now available to farmers also meant that large acreages could be planted to higher priced, more water intensive crops like rice.

Secondly, IIMI research data in sample watercourses of the LCC system indicated:

- extensive private tubewell developemet over the past decade with reported local densities between 5-10 tubewells per 100 ha rather common; and
- rapid development of private, shallow tubewells throughout the 1980's cushioned the declining pumpage of deep public tubewells and helped farmers maintain high cropping intensities of less drought tolerant crops.

Resultantly, the net irrigation applications in watercourse command areas continue to greatly exceed the orignal surface system design values of 1 lps for 5-7.5 ha. IIMI's data for 1988-89 (Vander Velde and Johnson, 1992) indicates public tubewell contribution, on average, to be 43% of all irrigation water for Rabi and 30% of irrigation supplies in Kharif. The overall contribution from groundwater accounts for between 70-90% of all irrigation water during Kharif and declines to < 50% of total water use during Rabi.

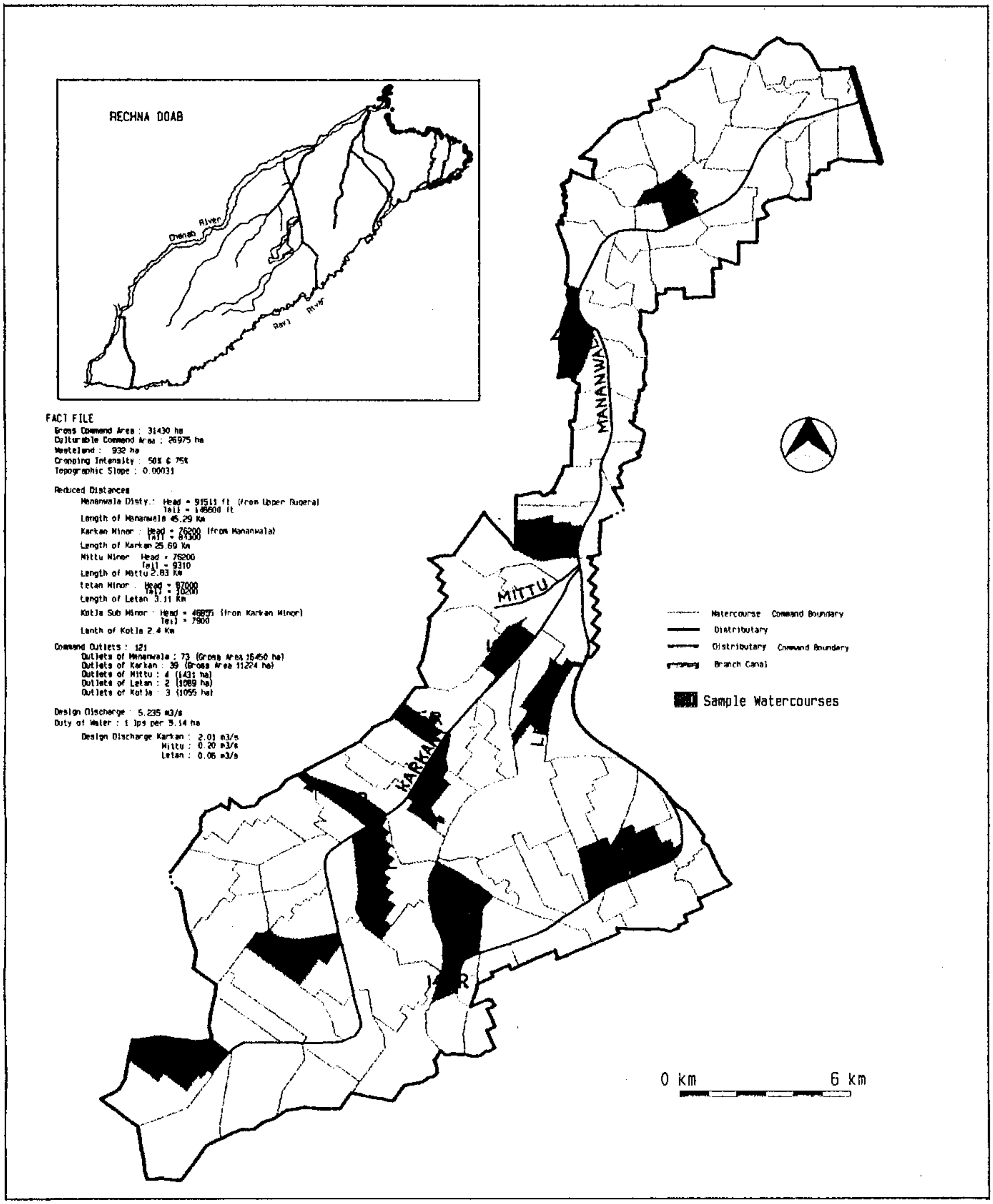
Not all farmers benefitted equally from this type of groundwater development; real equity in access to water pumped by public tubewells can only occur when they are located at the head of the watercourse. Often, public tubewells are located elsewhere within a watercourse command area so that only those farmers downstream are able to benefit. Additionally, some tubewells serve parts of two or more watercourse commands; some have a siphon that carry part of the discharge across distributaries, and others serve areas both outside the canal command as well as areas within it. Hence, local arrangements for accessing public tubewell water often are relatively complex. In some of the more complex situations, farmers may have both a canal water warabandi and a separate tubewell warabandi, while others have a single turn that mixes tubewell and canal water.

2) Utilization Strategies

Although the groundwater contribution from public and private sources may reach 70% of the total irrigation water used by farmers (Johnson, 1990), the utilization does not suggest that farmers are substituting groundwater for declining surface water supplies: groundwater is used as an *additive* to surface water rather than as a *substitute* source of water. Hence, in lieu of the chronic water shortages experienced in the tail reaches, the percent contribution of groundwater (to the minimum consumptive use requirements) increases from head to tail of each canal. The word consumptive use is relative and must be considered in the context of high and low delta crops. Downstream farmers grow low consumptive use crops due to the shortage of surface water supplies, hence the decline in total water use; the tendency is to avoid boosting pumpage to achieve the same cropping pattern and intensity as in the head reaches where the supplies are plentiful. IIMI research into actual water utilization rates during the peak periods of Kharif indicates that for the combination of surface and groundwater supply (and excluding the effects of rainfall) the overall relative water supply (RWS) for irrigated areas is slightly above 1, indicating the farmers are not pumping more than they need.

Based on the utilization strategies mentioned above, the estimation of a groundwater balance through differentiation in tubewell densities across irrigated commands is largely independent of the location along the command reach. Here IIMI's past research into Mananwala Distributary may be cited as an example, where not only detailed observations on surface flows and interseasonal cropping changes were made, but the conjunctive use regime was also studied over an extended time period in the sample watercourses (Figure 58). Based on a census of the tubewell population across the entire distributary, a mix of low to medium tubewell densities is encountered in the head reaches, which is not too different from the lower one-third reach of the distributary. The exceptions are in the middle reach, where the densities are significantly higher across a large cluster of watercourses (Figure 59).

Besides monitoring of the tubewell discharges and recurrent impact on the groundwater tables, water quality was also determined as a latent consideration towards emergent



FACT FILE
Gross Command Area : 31430 ha
Culturable Command Area : 26975 ha
Wasteland : 932 ha
Cropping Intensity : 50% & 75%
Topographic Slope : 0.00031

Reduced Distances
Mananwala Disty.: Head = 91511 ft (from Upper Gugera)
Tail = 148600 ft
Length of Mananwala 45.29 Km
Karkan Minor : Head = 76200 (from Mananwala)
Tail = 84300
Length of Karkan 25.69 Km
Mittu Minor Head = 76200
Tail = 9310
Length of Mittu 2.83 Km
Letan Minor . Head = 87000
Tail = 10200
Length of Letan 3.11 Km
Kotla Sub Minor : Head = 46895 (from Karkan Minor)
Tail = 7900
Lenth of Kotla 2.4 Km

Command Outlets : 121
Outlets of Mananwala : 73 (Gross Area 16450 ha)
Outlets of Karkan : 39 (Gross Area 11224 ha)
Outlets of Mittu : 4 (1431 ha)
Outlets of Letan : 2 (1089 ha)
Outlets of Kotla : 3 (1055 ha)

Design Discharge : 5.235 m3/s
Duty of Water : 1 lps per 3.14 ha

Design Discharge Karkan : 2.01 m3/s
Mittu : 0.20 m3/s
Letan : 0.06 m3/s

Figure 58 Location Map of Mananwala Distributary Command, Upper Gugera Division of the LCC System, Rechna Doab, Punjab, Pakistan.

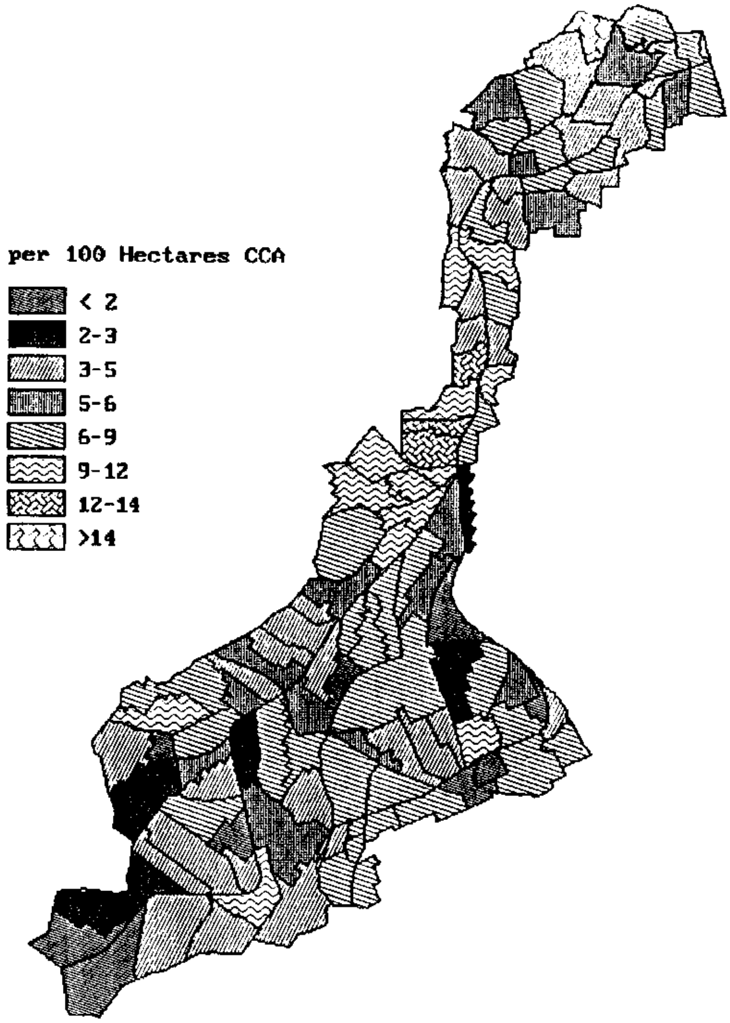
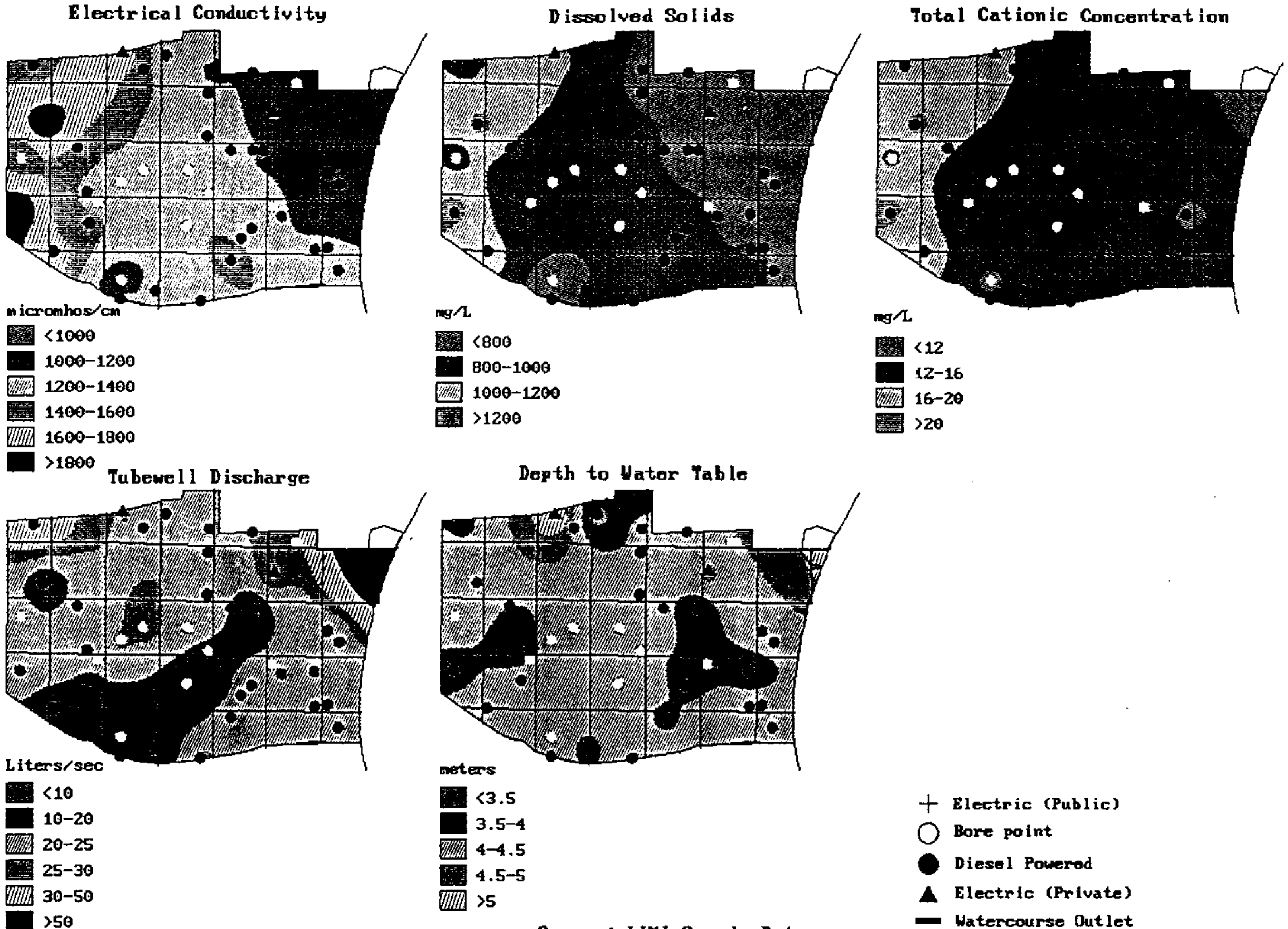


Figure 59 Tubewell Density in the Mananwala Distributary Command, Upper Gugera Division of the LCC System, Rechna Doab, Punjab, Pakistan.

utilization strategies. For the sample watercourse at RD 71, just upstream of the main channel trifurcation, the factors native to the groundwater regime, under potential exploitation by 40 private tubewells, appear in Figure 60. Given the relatively low discharge potential of tubewells (mostly under 25 lps), deep water and no apparent restriction on water quality, the overall contribution is close to the 70% figure reported by Johnson (1990) (Table 27). In comparison, the watercourse located at RD 121 near the tail of the main channel (Figure 61), which received between 30-44 percent higher surface supplies during the Kharif and Rabi period of 1990, pumped 30-60 percent less groundwater due mostly to somewhat poor quality of water from the shallow aquifer.

Thus, the upstream watercourse received less surface flows, but compensated through higher tubewell contribution to total supplies; the watercourse near the tail had somewhat higher surface supplies but given the lower tubewell density, influenced by poorer quality groundwater, the farmers opted to pump less towards total irrigation supplies. Clearly, the upstream watercourse represents a high consumptive use regime during Kharif that is fully exploited by higher tubewell densities. More realistically, there are variations to the pattern explained above, whereby farmers experiencing a severe deficit of surface supplies would adopt exploitation strategies that are both quantiatively and qualitatively at odds with the prevailing use across a somewhat more balanced regime elsewhere. Table 28 illustrates this more clearly in the comparison of Watercourses 114R and 143RB of Mananwala Distributary. Nothwithstanding the fact that both are located in the lower one-third reach of the channel, and that their respective tubewell densities were nearly similar, the net contribution of groundwater to overall irrigation requirements was drastically different amongst them. This difference was brought about by the near absence of surface supplies for the tail Watercourse 143RB. The farmers in this watercourse were forced to overwhelmingly rely on groundwater extraction to the extent that it exceeded the conjunctive use volume in the Watercourse 114R. Given the generally poor groundwater quality around the tail portions of the distributary, the repercussions of this singular reliance, brought about by the sheer need to sustain agriculture, are alarming indeed.

In areas of useable groundwater quality, the contribution from private tubewells may exceed 60% in the Rabi season and 80% in the Kharif. This is especially true for the reaches along the Gugera channel where the installed capacities of the private tubewells is anywhere between 7-18 times the designed canal supplies and 5-8 times the present discharges of public tubewells. Also, there are distinct differences between the ways various types of tubewells are used; according to a sample study in the Lagar Distributary command (Bhatti, 1992), the utilization rate for electric tubewells is almost 5 times that of diesel pumps and 4 times the rate for tractor-powered wells. The differences are mainly due to lower operational cost of the electric wells that encourages farmers to buy water from a nearby electric well rather than run their own diesel pumps. As a consequence, owners of electric wells sell more water than do other tubewell owners.



Source: IIMI Sample Data

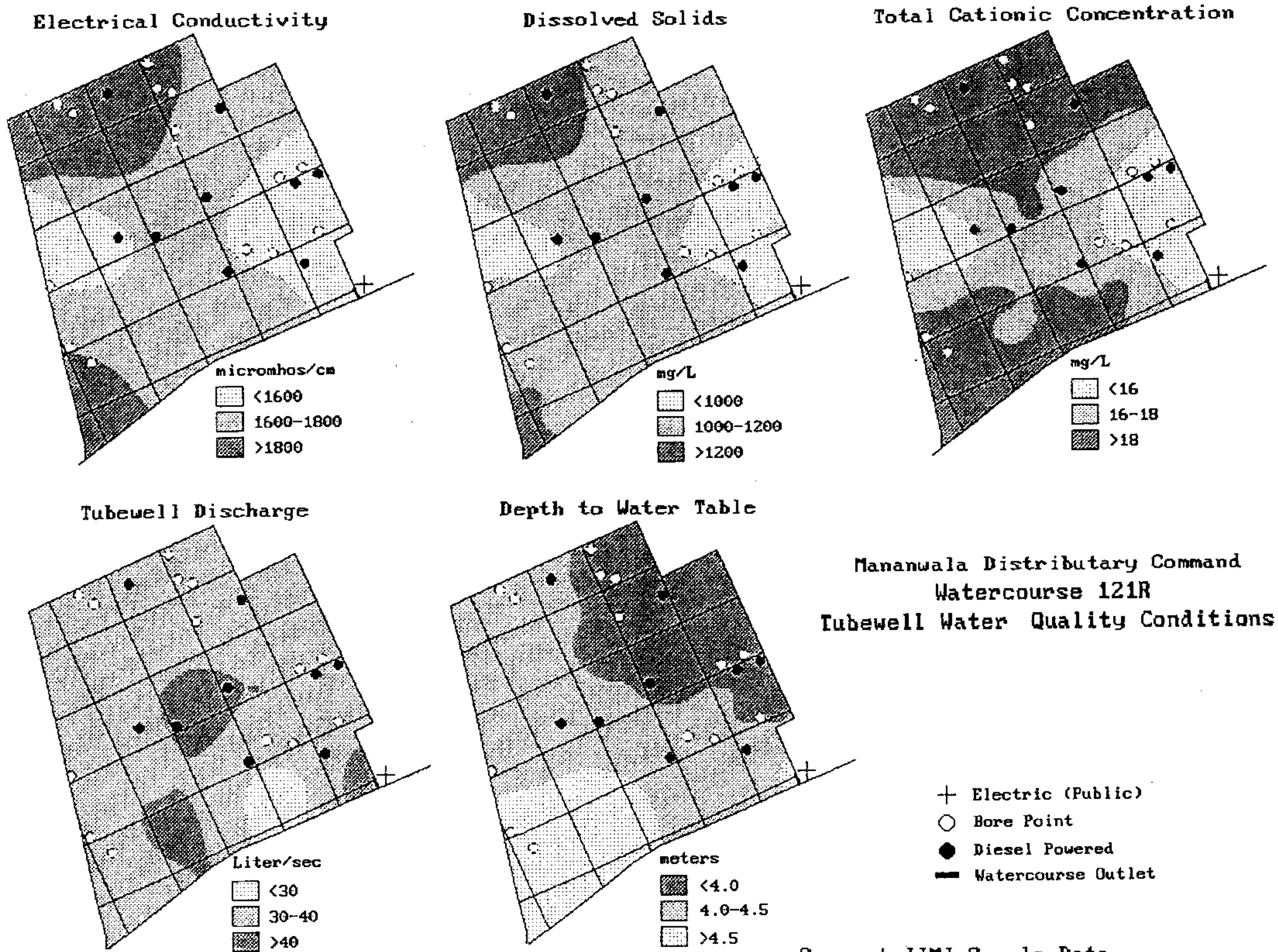
Figure 60 Map Representation of Parameters Associated with Quality and Quantity of Pumped Groundwater in Watercourse 71R of Mananwala Distributary (LCC System), Rechna Doab, Punjab, Pakistan.

Table 27. Percent Contribution of Groundwater to Total Irrigation Supplies in Mananwala Distributary of the LCC East Circle.

Sample Watercourse	Tubewell Density (per 100 ha CCA)		Groundwater Contribution	
	Kharif 1990	Rabi 1990	Kharif 1990	Rabi 1990
Mananwala Outlet 24-R	10.510640	10.510640	71.858	71.519
Mananwala Outlet 43-R	9.790989	9.790991	71.414	61.830
Mananwala Outlet 71-R	10.392710	11.778400	72.338	66.702
Mananwala Outlet 87-R	5.414840	5.414840	8.197	13.543
Mananwala Outlet 114-R	7.340910	9.500000	30.857	29.885
Mananwala Outlet 121-R	6.282989	6.282990	37.398	45.328
Mananwala Outlet 141-R	8.564223	8.564223	84.940	88.257
Mananwala Outlet 143-RB	9.233645	9.233644	100.000	97.032
Karlan Minor Outlet 10-R	4.433334	4.433334	63.182	76.543
Karlan Minor Outlet 25-R	3.337837	4.172297	35.359	10.212
Karlan Minor Outlet 27-L	2.004057	2.004057	12.349	50.000
Karlan Minor Outlet 36-R	2.392251	2.392252	60.850	69.604
Karlan Minor Outlet 37-LA	7.347825	7.347826	33.198	32.484
Karlan Minor Outlet 54-R	8.204547	8.204546	47.516	42.156
Karlan Minor Outlet 84-TR	3.351775	3.351774	39.772	61.860

Table 28 Comparison of Groundwater Utilization in the Mananwala Distributary (LCC East Circle) w.r.to Tubewell Density and Total Irrigation Application

Sample Watercourse	Tubewell Density (per 100 ha CCA)		Groundwater Contribution (%)		Irrigation Application (mm)				Total	
	Kharif 1990	Rabi 1990	Kharif 1990	Rabi 1990	Surface		Groundwater		Kharif	Rabi
					Kharif	Rabi	Kharif	Rabi		
Mananwala Outlet 71-R	10.392710	11.778400	72.338	66.702	242	159	635	319	877	478
Mananwala Outlet 87-R	5.414840	5.414840	8.197	13.543	611	361	54	56	665	417
Mananwala Outlet 114-R	7.340910	9.500000	30.857	29.885	596.3	445	184	133	780.3	578
Mananwala Outlet 121-R	6.282989	6.282990	37.398	45.328	315	229	188	190	503	419
Mananwala Outlet 141-R	8.564223	8.564223	84.940	88.257	63	33	354	253	417	286
Mananwala Outlet 143-RB	9.233645	9.233644	100.000	97.032		20	1049	662	1049	682



Source: IIMI Sample Data

Figure 61 Map Representation of Parameters Associated with Quality and Quantity of Pumped Groundwater in Watercourse 121R of Mananwala Distributary (LCC System), Rechna Doab, Punjab, Pakistan.

C. Incipient Salinity

In tandem with the research initiative for the study of canal system performance and the implications of conjunctive use, IIMI focused on the debilitating effects of salinization derived from the linkages between shortage of surface supplies and continued reliance on poor quality groundwater abstractions. The study of incipient salinity in the Upper and Lower Gugera commands benefited from the mass of data on canal supplies and tubewell operations already available in the sample watercourses of Lagar, Mananwala, Pir Mahal, and Khikhi distributaries.

1) Damage to Soils

IIMI's *field observations* point to a structural decline of soils resulting from irrigation with sodic groundwaters, a complication which poses an important obstacle to reclamation of saline soils by leaching. Sodic soils are typically hard to permeate and poor in tilth as a result of loss of structure and clay migration with the movement of sodic soil water. Groundwater quality sampling across sample watercourses indicated that 25% of the tubewells in the tail reach had EC and SAR values already within the range of waters likely to cause permeability problems. A rapid appraisal survey was mounted by IIMI in the command areas of seven watercourses of the Mananwala Distributary in 1989, to record the presence of salinity---either as surface salting of obviously salt affected crops and of dense, hard subsurface layers. Results hint strongly at a general deterioration in soil conditions towards the tail of distributary canal commands due to secondary salinity.

Another rapid appraisal survey in 1993, this time of the entire Mananwala Distributary, gathered *evidence* of surface salting or obviously salt effected crops and came to the conclusion that there was a general deterioration in soil conditions towards the tail of the distributary canal command due to secondary salinization (Figure 62).

Determinations of the mean salinity within the root zone in one-third to one-half of all fields sampled in the tail watercourse commands indicated profile salinity to be great enough to reduce crop photosynthesis even when the soil was at full field capacity. Unexpectedly, profile salinity in five percent of the fields sampled in the middle-reach watercourse commands had also reached this level, with the highest readings concentrated in surface-water-short tail areas of those watercourses. Under such conditions, crops are stressed even though there may be plenty of moisture in the soil.

2) Loss of Productivity

Siddiq (1994) conducted a study during Rabi 1991 on effects of salinity and sodicity on wheat yields in the commands of Mananwala and Pir Mahal distributaries of the LCC system. He concluded that farmers are largely unable to mitigate soil sodicity problems and

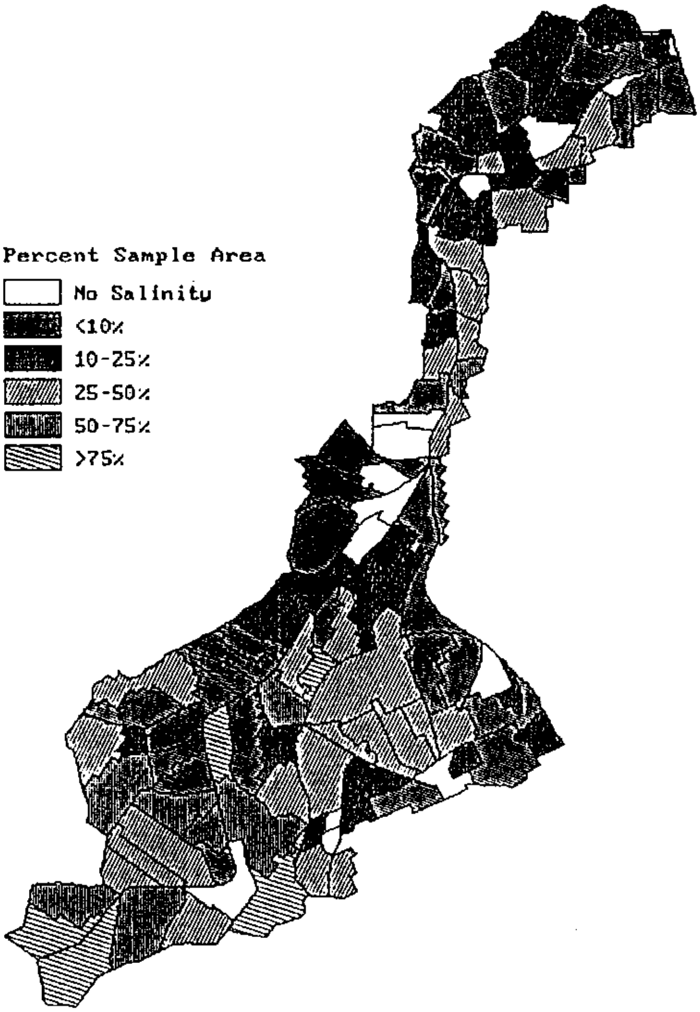


Figure 62 Distribution of Visual Salinity in the Mananwala Distributary Command, Upper Gugera Division of the LCC System, Rechna Doab, Punjab, Pakistan.

as a result lose about 411 kg/ha of wheat yield in the Mananwala command and 231 kg/ha in the Pir Mahal command. From amongst IIMI's sample observations on wheat, ECa of 10 dS/m could be expected to cause a reduction in the yield up to 40 percent or a decline of as great as 60 percent in the yield of sugarcane (these are indicative values only since the salinity tolerance of crops can vary with ambient agronomic conditions, cultivation practices and other production limiting factors).

3) Root Zone Simulations

Simulation modeling to predict water and salt movement into and out of the rootzone for three major crops of the LCC system (i.e cotton, wheat, and sugarcane) indicated that actual leaching fractions for wheat are sufficient to reduce profile salinity. For other crops, and for all soil textures tested with the model, profile salinity increased. The largest increase takes place in sugarcane grown on silt loam with irrigation water of 2.5 dS/m. Another important observation is that leaching is far more effective for wheat during the cooler Rabi season that for crops grown during the hot Kharif season, even though monsoon rainfall exceeds that from winter rains. These simulations used both the median and 75% EC values of irrigation water being pumped by tubewells that are used by farmers in tail-end watercourse commands. Median irrigation applications for wheat grown in the Mananwala Distributary command, and for cotton and sugarcane grown in the command of Pir Mahal Distributary were used as input in the model.

4. Management Options for Leaching Fractions

The declining trend in groundwater quality towards the tail of the distribution system (based on a sample of 28 watercourses within the Gugera system, Figure 63) concurrently necessitate an increase in leaching fractions to avoid secondary salinization in the root zone. While the relative water supply (RWS) figures for the Kharif cropping pattern (Figure 64) show values close to 1, thereby indicating pumpage sufficing only for consumptive use, the ominous repercussions for salinity build up as a result of this *efficiency* are all too clear. Management interventions, such as the ones listed below, for the containment of the emergent threat are unlikely to succeed in the wake of farmers perceptions about productivity being inseparably tied to quantum of supplies available through an increasingly inflexible system already pushed to its operational limits.

- Redistribution of surface supplies along a canal may arrest the rate of salinization in tail end areas, but it cannot eliminate it. Calculations indicate that it requires an increase of at least 50% in surface water supplies and a reduction in pumping of 20% to provide the correct balance of poorer and better quality waters to the tail reaches. The present physical condition of the system precludes a 50% increase in supplies; attainment of the 20% calculated reduction would be stretching the imagination.

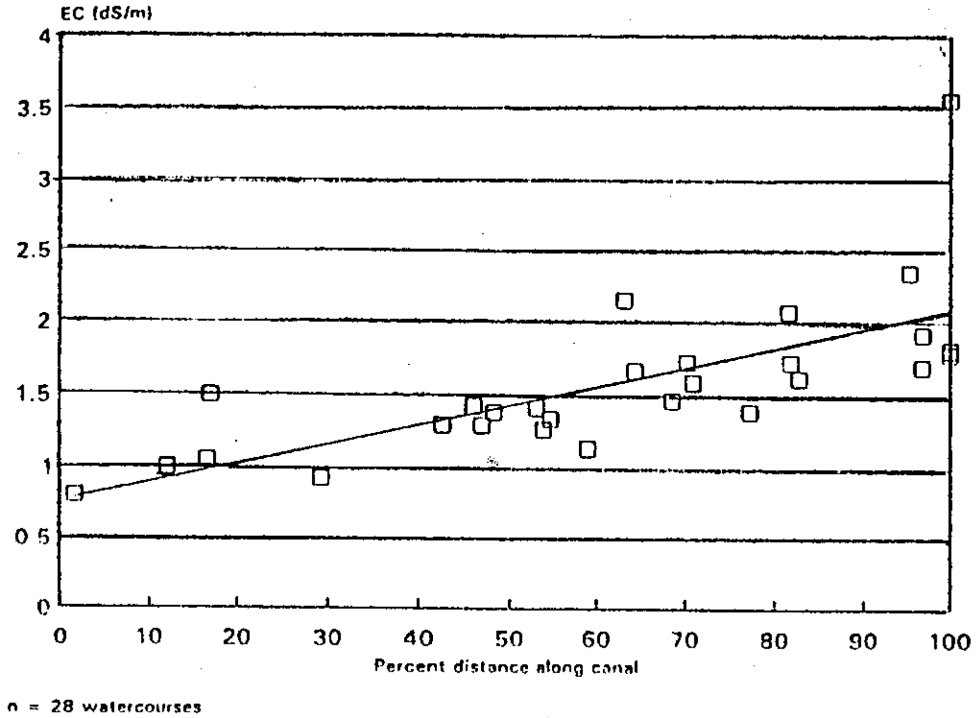


Figure 63 Average Tubewell Water Quality in the Sample Watercourses of the LCC System, Rechna Doab, Punjab, Pakistan.

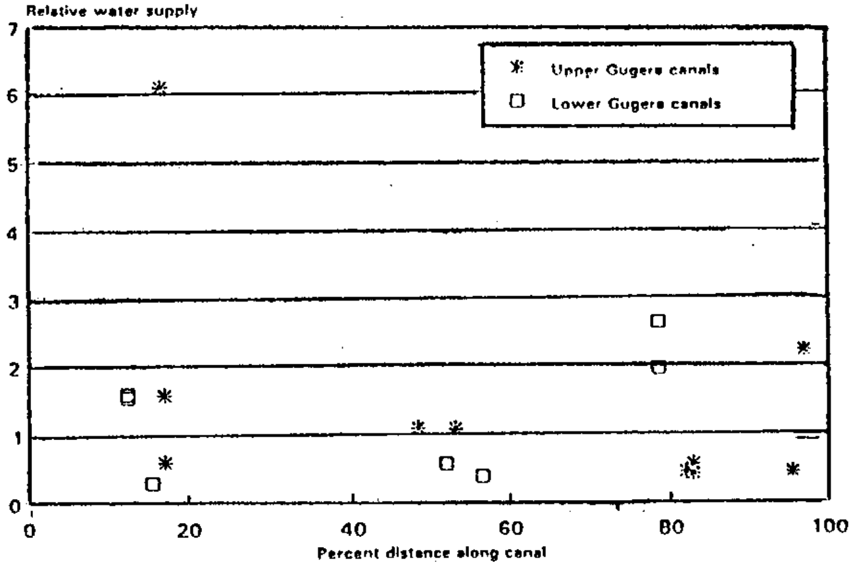


Figure 64 Irrigation Water Supply for Non-Rice Crops of the LCC System, Rechna Doab, Punjab, Pakistan.

- Assuming no significant changes in current cropping patterns, the objective of bringing the average EC value of the mixed irrigation water available to middle and tail watercourse commands below 1 dS/m seem certain to require greater quantities of canal water for mixing than are presently available within the Gugera system.

- Greater groundwater use in FGW areas (EC < 1200 micromhos/cm) may appear attractive, but if the proportion of use increases from the current 60-70% to the 85% typical of the tail reaches, it is likely that salinity build up will also be accelerated.

- An increase over and above the sanctioned supply to accommodate the leaching fractions would be consumed entirely towards higher consumptive use crops in the upper reaches of the system without any relief for the users downstream.

An alternative, and one that is already occurring in parts of Punjab, is the reduction of the irrigated area through reduced frequency of cultivation. From a technical and agronomic perspective, it is probably rational to allow this to happen, and to concentrate higher quality water on a smaller area with improved irrigation and agricultural practices. However, with limits even to this rationality, the dynamism of change would necessitate focused solutions that are better adapted to management strategies evolving out of pragmatic research.

XI. ENCOMPASSING THE SALINITY MANAGEMENT ALTERNATIVES

In many ways, given the diversity of the cropping patterns, potential rainfall, and soil types, Rechna Doab could be considered to be the bread basket of the country. It has also been the forerunner to much of the intensive surface and groundwater irrigation development and land reclamation schemes within the country. Much of this development had been punctuated, both before and after independence, with intensive studies of the changes occuring across the landscape due to shifting patterns of land use and resource utilization. Against the backdrop of massive public and private sector investments towards boosting agricultural productivity, too often on a scale grandiose by current levels of undertaking, the solutions have met with mixed success in ensuring sustainable development into the future. However, the past decade or so has seen a refocusing of the public sector priorities that directly address food security issues leading into the 21st century. It appears that somewhere within the growing milieu of advances in gene mutation, genetic engineering, disinvestment and decentralization, pesticide and fertilizer applications, infrastructural and varietal payoffs lies the key to sustainability of the irrigated agricultural system. Perhaps the key word here is ***integration*** which nonetheless devolves around the physical scale and scope of interventions envisaged for sustainability. The foregoing sections I-X have permitted a gradual descent in time and scale to the crux of the problem and perhaps a prelude to a plausible mix of solutions that are functionally and economically predictable and tempered with realism.

Much of the emergent focusing of management and capital intensive assails at the policy formulation stage in recent years has been anchored to the recommendations brought forth by the RAP, the prioritized enunciations of the succesive Five Year Plans since 1983, and the selective appraisal of public projects by the WSIP. The targeted redemptions in agricultural growth rates put forward by the NCA, cognizant of the bulging population, have been the catharsis for prioritized ranking of many public sector projects at the federal and provincial level. However, at best, these investments would secure the ***mechanisms*** needed to enhance productivity but would stop short of the ***optimizations*** coincident with variable growth rates and selective resource mobilizations that are invariably scale specific. Moreover, the capitalizations from sectoral investment are less likely to integrate within and across their respective objectives, or for that matter, entail moorings to collective growth in the predictable future. Of course, in the wake of preferential mechanisms, such as the WSIP shortlists, the task of integrated assessments is further compromised and what remains is a composition that is largely distributed in time and space.

Rechna Doab's geographical size does not favor piecemeal approaches to resource optimization. In fact, given the pressures of land fragmentation necessitating higher productivity, the resource worthiness of the farming community has been stretched to the thresholds of gains from the investments of yester years. Now, the past project-wise distinctions of returns to scale have blurred to represent a new balance in irrigated agriculture. And since water is the primary input and constraint to any furthering of the gains thereof, consideration of the strategic options must take into account the current ranking of the land use and the most likely scenario for its sustained growth.

Set in the backdrop of the past reclamation and investment strategies, IIMI's appraisal of the irrigated landscape across the Rechna Doab aims to:

- integrate the physical and chemical characteristics of the regime for stratified consideration of resourcefulness across irrigation units;
- develop a predictive capability for continued reliance on the groundwater regimen, wherever feasible;
- model the returns to scale and production enhancements amidst the threat of land degradation; and
- predict the likely impact on cropping patterns in lieu of augmentation of surface and groundwater supplies.

The above assemblage derives much of the inference from the past public and other investigations into the physical and qualitative details within the Rechna Doab. For each element of information, there is a corresponding reference to its physical location, and the means to this temporal and spatial integration are derived on the basis of a computing capability bracketed under the name of ***geographic information systems*** (GIS). In fact, the spatial linkage across the entire gamut of strategies listed above lends itself to be the fundamental building block of the assignment undertaken by IIMI. The use of thematic modeling sets this course apart from the conventional appraisals conducted for project development. In Volume Three that follows this discourse into the history of Rechna Doab's irrigated agriculture, the procedural and analysis links for this strategy will be explained.

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